"USER REQUIREMENTS FOR THE COMMERCIALIZATION OF SPACE"

TASK 3 - FINAL REPORT - SEPTEMBER 1983

CONTRACT NASW - 3674

The focus of this report is to assess the interests and needs of the non-aerospace industry in light of the prospects for product development in space. The fundamental feature is the detailed account of visits to selected non-aerospace industries. This report is aimed at the establishment of a space commercialization constituency.

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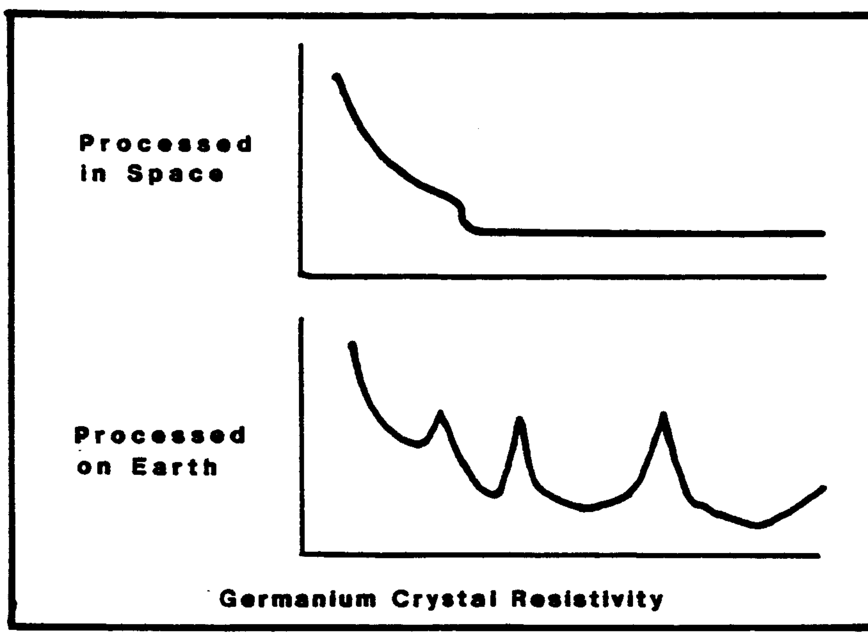
"USER REQUIREMENTS FOR THE COMMERCIALIZATION OF SPACE"

CONTRACT NASW-3674



TASK 3 - FINAL REPORT
SEPTEMBER 1983

PREPARED FOR:
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WASHINGTON , D.C. 20546

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SPACE STATION COMMERCIALIZATION

TASK 3 - FINAL REPORT

CONTRACT NASW-3674

"USER REQUIREMENTS FOR
THE COMMERCIALIZATION OF SPACE"

PREPARED FOR:

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
NASA HEADQUARTERS
CODE LG-2
WASHINGTON, D.C. 20546

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SEPTEMBER 1983

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I. FOREWORD

This report is written in fulfillment of Contract NASW-3674 entitled "User Requirements for the Commercialization of Space." It was prepared by ECOsystems International, Inc. for the National Aeronuatics and Space Administration Headquarters, Office of Industrial Affairs, Technology Utilization Division.

The overall goal of this project was to assess non-aerospace industry perceptions of and interests in pursing commercial operations in near-earth orbit. Two steps were taken to augment this goal:

- The status, results and potential of the art of Material Processing in Space (MPS) were synthesized with a view to commercial processes which would be significantly facilitated or improved in an earth-orbit space environment.

- Queries of selected U.S. non-aerospace industries were completed which identify opportunities for NASA to gain industrial involvement in space-based applications of materials processing.

From these summaries of MPS research, and responses to industrial queries, the MPS component of a cost-effective earth-orbiting space station may be inferred on the basis of user requirements and plausible research and development.

II. EXECUTIVE SUMMARY

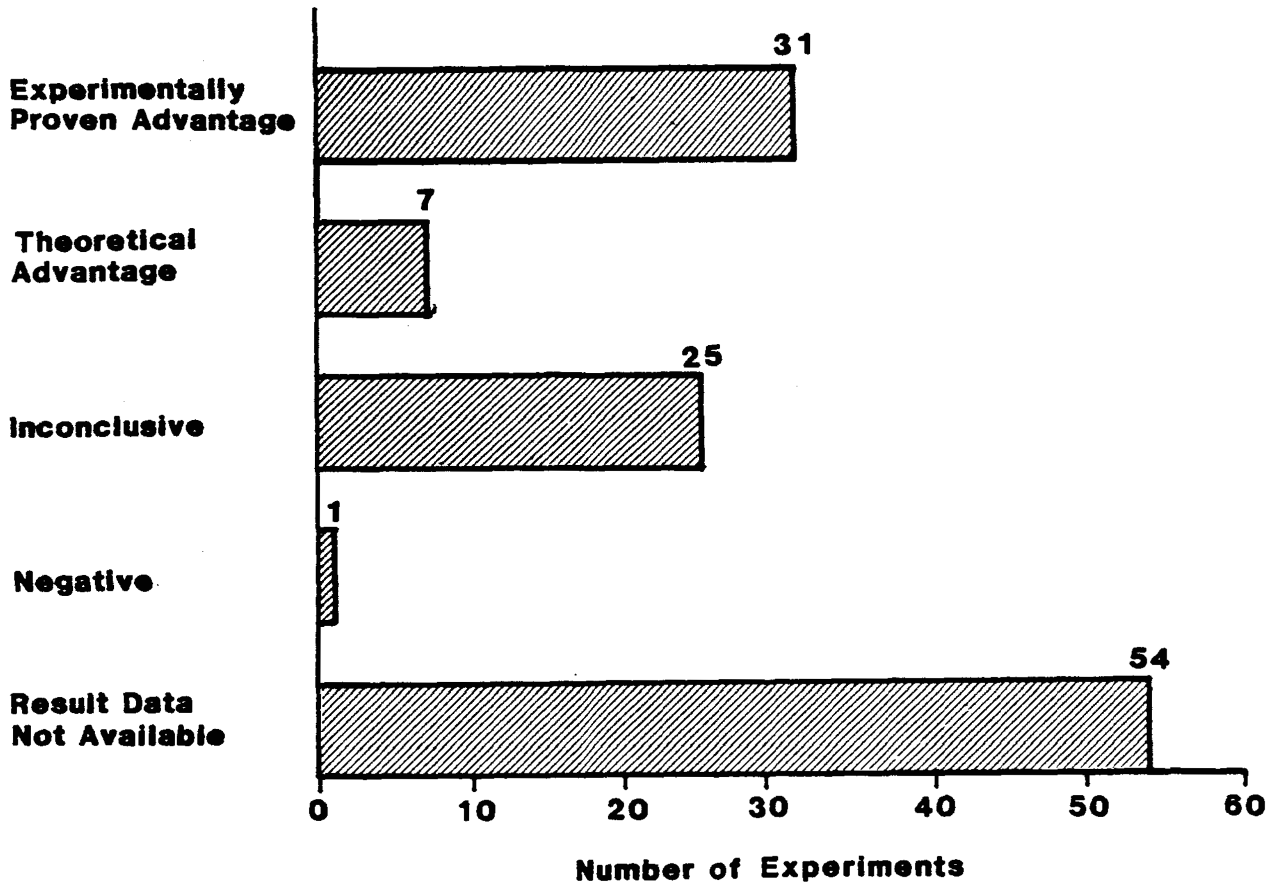
2.0 Overview

This report represents the final discussion and results of Contract NASW-3674 entitled "User Requirements for the Commercialization of Space". Its focus is to assess the interests and needs of the non-aerospace industry in light of the prospects for product development in space. The approach in this report is based upon the Application Development marketing technique which matches user requirements and interests with areas of promising Research and Development results. It complements a number of parallel activities being conducted under the auspices of NASA Headquarters and Field Centers.

In order to provide the technical basis for planned discussions with potential space commercialization user industries, a significant part of this effort was concentrated on the collection of Materials Processing in Space (MPS) Program experiment data and the analysis of their results. In addition, visits to some 16 potential MPS users were made in order to appraise the level of the non-aerospace industry's knowledge of MPS and their interest in pursuing the techniques for eventual commercialization.

This report provides a synthesis of what has been and what can be accomplished in materials processing in the space environment. MPS experiments were divided into four categories: demonstration of processes, demonstration of special effects of the space environment, theoretical analyses, and development of experiments/techniques. Results from these experiments were then gleaned, categorized and divided into seven areas: major technical and promising economic advantages; experimentally proven advantages; theoretical advantages; inconclusive results; faulty experiments; negative results, and results proprietary or not available, see Figure 2-1. Upon completion of the above steps, the positive and promising results were extrapolated and their expected potential defined. All experiment data and steps have been integrated with information from the Marshall Space Flight Center (MSFC) and other NASA centers.

The fundamental feature of this report is the detailed account of visits to selected non-aerospace industries. It provides a sample data base of industry's perspectives, motivations, and interests in participating in space materials processing activities for



Breakdown of Experiment Results

Figure 2-1

profit; it ascertains the validity of the postulated format for interfacing with the non-aerospace industrial community. The visits proved to be generally encouraging. Most R&D managers were aware of NASA's space commercialization activity and interested in its potential. They were handicapped, however, by limitation of available time to analyze, in depth, the application of MPS technology to their industry's requirements. Nevertheless, they evidenced a willingness to enter into further discussions directed toward areas of specific technological interest to their industries. This report, therefore, contains a preliminary proposal for instituting a process that would accommodate these factors in the pursuit of NASA's objective, i.e., the establishment of a space commercialization constituency.

2.1 Conclusions

The conclusions resulting from this report are as follows:

- The results of MPS investigations performed up to 1980:

  - Are far more numerous and interesting than is commonly perceived;
  - Are not readily available in a centralized repository;
  - Suffer from a lack of operational space processing equipment and sufficient low "g" flight time;
  - Are formulated in a technical terminology not readily translatable to potential industrial users;
  - Show near-term promise for the manufacture of high value pharmaceuticals;
  - Show longer-term promise for the commercial development of materials requiring high degrees of structured control.

- A number of space experimentation apparatus have been developed. Several of these could also find use in terrestrial applications.

- Discussions with potential industrial users of MPS commercialization have shown:

  - Interest on the part of R&D managers (see Figure 2-2);

Industry Response to MPS Query

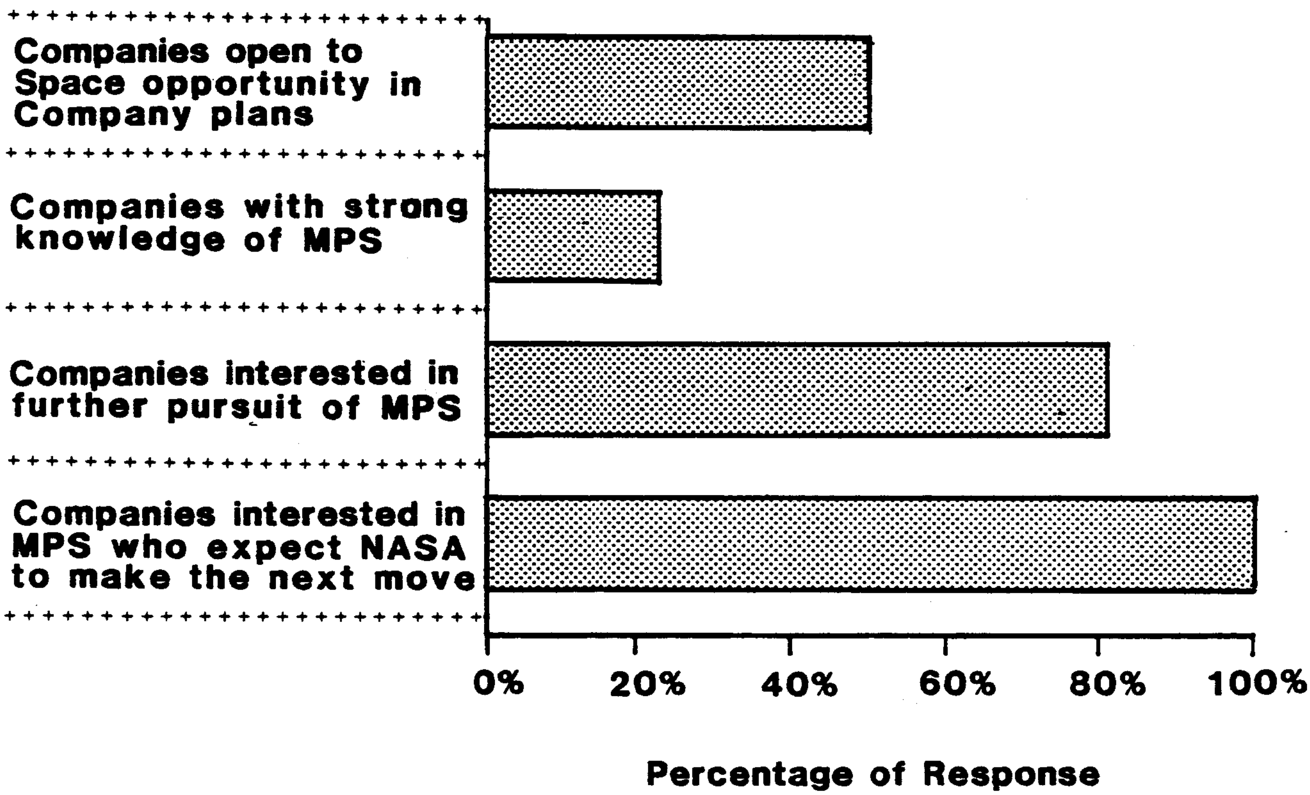


Figure 2-2

- MPS commercialization overtures should be focused on areas of specific application to each user;
- A willingness by users to devote resources if they perceive real possibilities for space commercialization; and,
- Their desire to have NASA organize an agenda of personal dialogues and presentations on MPS between high-level officials from both NASA and industry.

2.2 Recommendations

The recommendations resulting from this report are as follows:

- A centralized data source of MPS program results should be established.

- MPS program results should be cast in industrial terminology accessible to industry.

- MPS program results should be used to stimulate industrial thinking and latent creativity.

- A characterization and description of space experimental and processing apparatus should be included in commercialization endeavors.

- NASA space commercialization efforts should consider, in addition to MPS, the development and space deployment of large antenna structures for communications.

- An organized NASA space commercialization effort should be presented to potential space commercialization users with an emphasis on NASA's incentives for the use of Space Transportation Systems and eventual use of the Space Station.

- Since industry will expend time and money predominantly on the application of results which show definite promise of commercial utilization, NASA should concentrate efforts on MPS areas of experimentally proven promise and reconsider the emphasis to be placed on efforts in those areas which show little immediate promise.

III. BACKGROUND AND OBJECTIVE

3.0 Background

Since the inception of its activities, NASA, in the interest of industrial development and varied public service, has pioneered the use of the unique physical properties of space. This exploratory venture has given rise to well-known technological spinoffs — communication satellites, atmosphere and earth observation space systems, and the growing industry of privately-owned space launchers and service satellites.

Throughout the last decade, NASA has intensified its investigation of the exploitation of certain properties of the space environment — primarily low gravity and high vacuum — to improve industrial processes. NASA has performed approximately 130 theoretical and experimental investigations of Materials Processing in Space (MPS) either in simulated space conditions or in conjunction with actual space flights. Simulated space conditions were created through the use of drop facilities, aircraft in parabolic trajectories, or coasting rockets. Actual space conditions for MPS experiments were realized on Apollo, Skylab, Apollo-Soyuz Test Project (ASTP) and, most recently, Space Shuttle flights. Moreover, NASA's newest planned endeavor, the earth-orbiting Space Station, will serve as a test bed for MPS.

The MPS Program was selected for this investigation because of its experimentally proven potential as a viable component of a Space Station. While other areas associated with a Space Station might have been addressed, ten years of work in MPS represent an excellent index of industrial interest in the commercial utilization of a Space Station.

3.1 Objective

The principal objective of this report is to apprise NASA of U.S. non-aerospace industry perceptions regarding the advantages and disadvantages associated with commercial operations in near-earth orbit. This information will be used by NASA as an input toward determining the configuration and technical specifications of an earth-orbiting Space Station. In support of the this objective, a synthesis of the status, results and promise of MPS Research and Development was compiled in order to relate NASA's capabilities and technology to non-aerospace industry requirements.

IV. STUDY METHODOLOGY

4.0 Purpose

In this section, an economically realistic and profitable approach to the commercialization of space is identified and defined.

In essence, commercialization of space involves developing the most cost-effective technology possible that would induce a suitable segment of the industrial community to utilize the space environment for profitable purposes. Consistent with marketing theory, this is supplemented by two principal tasks:

- Identifying the market
- Approaching and capturing the market

Since the advent of the industrial revolution, industry has developed, through repeated trial and error, these methodologies for identifying and successfully approaching the market with its products and services. They are currently employed throughout industry and are summarized in the following.

4.1 Identification of the Market

In industrial terminology, the population of potential customers is categorized in terms of "gross", "addressable" and "capturable" markets.

Gross market designates the total population of possible customers for a given industry's products or services. Thus, for example, the gross market for MPS includes all industries which produce materials, and/or which process materials into added-value products.

The addressable market, a sub-class of the gross market, consists of those potential customers whose requirements for products and/or services relate closely to the products and/or services being offered by the "selling" industry. In the case of MPS, the addressable market includes industries which either:

- Produce products of high specific value, i.e., high cost per unit weight; or

- Engage in "exotic" processes whose intimate workings are not fully understood, and which could therefore benefit from additional insight through R&D efforts. In order for a process or product to be genuinely addressable to this market, its potential benefit must be expressable in terms of increasing potential sales or profits from improved understanding of the process and consequent improved characteristics of the product, or more efficient performance of the process.

The capturable market is that segment of the addressable market which will actually purchase the products or services being offered. Thus, in the case of MPS, the capturable market represents those customers who can be expected to eventually benefit from MPS activities in concert with NASA. Note that the term "MPS activities" encompasses the end-to-end sequence of steps which begins with exploratory information exchanges and ends with purposeful experimentation and/or operations in the space environment.

Identification of the addressable and capturable markets is not an exact science, but is refined more precisely through experience. The addressable and capturable markets are statistical rather than deterministic concepts. They become deterministic after the sales are actually completed.

4.2 Approach to Market

A number of approaches have been developed by industry for capturing a suitable share of the addressable market. Existing approaches are variants or combinations of two principle methods:

- The canvass method, and
- The applications development method.

In the canvass approach, the seller seeks to elicit customers from within the base of the addressable market by offering his product or service to the prospective customers on a statistical basis. The seller relies on the assumption that a certain percentage of prospective customers will be converted to "captured" customers. Because the basis for conversion from addressable to captured market is statistical, the assumption underlying the canvass approach is that the greater the number of prospects contacted, the greater the total number of customers there will be.

In the applications development approach, the seller starts by learning the prospective customer's business; he then markets his product or service in such a way as to provide specific economic advantages to the prospective buyer. In other words, the seller does not rely exclusively on the prospective buyer to determine the usefulness of the offered product or service; rather he markets a "result" demonstrably benefitting the buyer, i.e., predicated upon the buyer's capacity to use the seller's product or service.

The main criterion which should be applied in choosing a marketing approach is cost/effectiveness, i.e., the ratio of sales to the cost of the resources expended to produce the sales.

The canvass method has proven to be most cost/effective in cases where the application of the product or service is obvious or readily conceived by the prospective customer. This is the case, for example, of consumer products.

The applications development method has demonstrated maximum cost/effectiveness in cases where the product or service offered is not obviously related to the prospective purchaser's advantage. This is generally true of complex, high technology processes. A typical example is offered by the introduction of computers during the fifties. The potential buyers had difficulty in associating the use of computers with their business needs. Successful computer manufacturers approached this marketing problem by intially analyzing their prospects' operations. They then configured and presented their product in terms of a service which would increase the industrial productivity of a targeted customer's operation.

The applications development method has been selected for use in this study. While the canvass approach has been and is still being employed by NASA in other space industrialization efforts, the applications development approach should reach and effectively influence a wider base of interested industries. Moreover, it will allow NASA to compare the results achieved by the two methods.

As applied to the work plan of this study, the applications development method may be summarized in the following steps:

- Characterize the space environment and identify its unique properties;
- Isolate the exploitable effects of the space environment in general and define, qualify, and quantify those characteristics specifically applicable to MPS techniques;
- Derive and categorize the proven applications of these effects, i.e., the results achieved thus far in NASA's MPS effort;
- Summarize the most promising payoffs anticipated from MPS, based upon the expected experimental and/or theoretical results to be achieved;
- Identify corresponding candidate commercial products and processes which could be improved and enhanced through MPS;
- Identify specific industries as candidates for manufacturing these products or using these processes;
- Initiate a program of direct queries of these industries to assess their interest in and their reservations and potential difficulties with the use of the space environment for profitable ventures; and
- Delineate a modus operandi by which NASA can interface with the candidate industries.

Initial contacts with prospective MPS customer industries suggested the overwhelming importance of proven, documented MPS results; or, as a minimum, of experimental data points and sound theoretical inferences. Thus, a major share of this effort was devoted to culling "results" and inferred potential results from available literature on MPS and from contacts with NASA centers. A synthesis of these results is presented in Section VIII.

A brochure, containing a short summary analysis of MPS concepts and results, was conceived to facilitate discussions with various industries, by stimulating their interest in learning more of NASA's activities directed at the commercialization of space. A draft of a conceptual brochure was attached to the Task I Report, May 1983.

V. DATA SOURCES

5.0 General

Initial inquiries suggested the compelling need of industry to be apprised of current MPS results before direct, substantive communication on MPS could take place. Therefore, research for this report was directed in two areas: 1) specific MPS experiment information was compiled and, 2) direct queries of selected non-aerospace industries, regarding MPS, were elicited and then analyzed.

5.1 MPS Data

The non-aerospace industry, by and large, was found to be uninformed of specific MPS experiments and results. Therefore, a significant portion of this study was aimed at pulling together MPS experiment summaries and results.

However, MPS experiment summaries and results were not readily available. There is apparently no central organization or data bank from which this information could be derived. Obtaining the data, therefore, proved to be a difficult and time consuming effort. In due course, the necessary data were finally gleaned from five major sources: NASA Technical Memoranda (TM), Principal Investigator (PI) and Contractor Reports, Proceedings of Conferences, Journal Articles, and articles derived from Bibliographies of MPS literature. Table 5-1 illustrates examples of the specific type of information available in these sources. A complete listing of all literature sources is contained in the bibliography (Appendix B).

The bulk of the MPS data were derived from NASA TMs. They encompassed the Apollo, Spacelab, ASTP, and SPAR Missions. The TMs contain experiment objectives, experiment discussions and some experiment results. Although the TMs were an excellent source of MPS Program data, there were significant gaps in the discussion of results in these documents.

To supplement NASA TMs, Principal Investigators (PIs) were contacted. Sixty five letters were sent requesting specifics on the latest results of their experiments. A copy of one of these letters in included in Figure 5-1. In addition, three phone calls were

TABLE 5-1

EXAMPLES OF DATA SOURCES

I. NASA Technical Memoranda

- Naumann, R.J., 1979. Early Space Experiments in Materials Processing. NASA TM-78234
- Pentecost, E., 1982. Materials Processing in Space. Program Tasks. NASA TM-82496

II. Principal Investigator and Contractor Reports

- Gelles, S.H., E.W. Collings, W.H. Abbott, and R.E. Maringer, 1977. Analytical Study of Space Processing of Immiscible Materials for Super-conductors and Electrical Contracts. NASA CR-150156.

III. Proceedings of Conferences

- Marshall Space Flight Center, NASA, 1974. Proceedings of the Third Space Processing Symposium — Skylab Results (2 volumes).

IV. Journal Articles

- Covault, C., 1982. Payload Tied to Commercial Drug Goal. Aviation Week and Space Technology, May 31 Issue.

V. NASA Bibliographies of MPS Literature

- Pentecost, E., 1982. Materials Processing in Space Bibliography. NASA TM-82466

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August 10, 1983

D. J. Creed Clayton
Semtec Inc.
Huntsville, Alabama 35804

Dear Sir:

ECOsystems is in the process of preparing a comprehensive index report for Code LG-2, NASA headquarters, which is a compilation of current results from Manufacturing Processes in Space investigations.

Your activity on Transient and Diffusion Analysis of HgCdTe appears to us to be of significant importance to this program. In order to fulfill our task, we would very much appreciate obtaining the latest results from your Principal Investigator activities and analysis and any other pertinent information which you desire to report.

Please send us as much of this material as you can. We will provide full credit to your material in our compilation.

Your cooperation will be greatly appreciated.

Dr. Andrew G. Adelman

Dr. Andrew G. Adelman
Research Center Director
ECOsystems International, Inc.

Figure 5 - 1

Sample Letter to Principal Investigators

made to those PIs that could be located. Less than ten percent of the PIs that were contacted responded with updated information; ten of the contacted PIs had moved without leaving forwarding addresses, and thus, not reached at all. (This was expected since a number of these experiments date back ten years or more.) Nine respondents sent copies of old papers — adding little to the updating process; three of these respondents, however, contributed a wealth of updated results which were incorporated into the Results Table.

Journal articles, besides providing summaries of specific experiments, included a few results not contained in the TMs. Some of these results addressed the industrial uses of space and Space Shuttle MPS payloads.

Proceedings from conferences provided excellent discussions and some results of successful and potentially successful experiments.

Other sources provided cogent background information and a general perspective on MPS. Selected books provided historical analyses of the American and Soviet MPS and Space industrialization programs. Statistical information was retrieved from Federal agencies, including the Department of Commerce, the National Science Foundation, the General Accounting Office, and the Senate and House testimonies on NASA appropriations. Catalogs of product lines and price lists were obtained from a variety of U.S. manufacturers, particularly in the areas of high value pharmaceuticals and chemicals, which provided a data base of material prices. Finally, two visits were made to the Marshall Space Flight Center, and individuals from the Lewis Research Center who are currently involved in the MPS Program were contacted by phone. Representatives from these facilities provided excellent sources of information concerning past and ongoing efforts related to space commercialization experimentation.

5.2 Industry Surveys

As specific examples of what materials processing in space can accomplish, the salient results derived from prior MPS experimentation were presented to selected U.S. non-aerospace industries. Extensive discussions with personnel from these industries were then conducted to assess industrys' interest in, and identify potential problems with their involvement in the use of the space environment.

The results of these discussions were then compiled in a uniform survey format, shown in Chapter 10 of this report.

Seventeen companies were targeted for the surveys. Their selection was based upon a desire to assess companies within a wide range of sales volume and end-products produced.

The information derived from these interviews provides a cross-section of the perceptions of MPS by U.S. non-aerospace industry representatives. A compilation and discussion of these interviews is included in Chapter 10.

VI. SPACE ENVIRONMENT PROPERTIES

6.0 General

The key to the commercialization of space is to identify those space environmental characteristics which are exploitable for commercial purposes, i.e., those characteristics which could be utilized to directly foster industrial processes in space or increase the understanding of how such processes function on Earth.

In this section the exploitable characteristics and effects of the space environment are examined by using the "Top-Down" approach. First, the basic properties of the space environment are explained and their effects are identified and quantified by comparison to those occurring at the Earth's surface. Secondly, the current status of exploration or utilization of these effects for scientific or commercial purposes is explored. Finally, those effects that are unique to the space environment, that is, not readily reproducible or impossible to reproduce on Earth, are identified for further analysis.

The "Top-Down" tree is shown in Figure 6-1. Its explanation is provided in the subsections which follow, and in Section VIII.

6.1 Isolation of the Principal Effects of the Space Environment

The environment of a spacecraft in Earth orbit is characterized by: (1) low gravity; (2) the rarefaction of the medium; (3) specific types of background radiation; and (4) synoptic overview of the Earth's surface and atmosphere.

The latter effect, i.e., synoptic overview, has given rise to the important discipline of remote sensing from space. Because it is currently approaching successful commercialization, it lies beyond the scope of the present effort and will not be considered further in this report.

6.2 Low Gravity

In Earth orbit, the centrifugal force acting upon the spacecraft equals the centripetal pull of gravity. That is to say, although gravity is active in Earth orbit, its

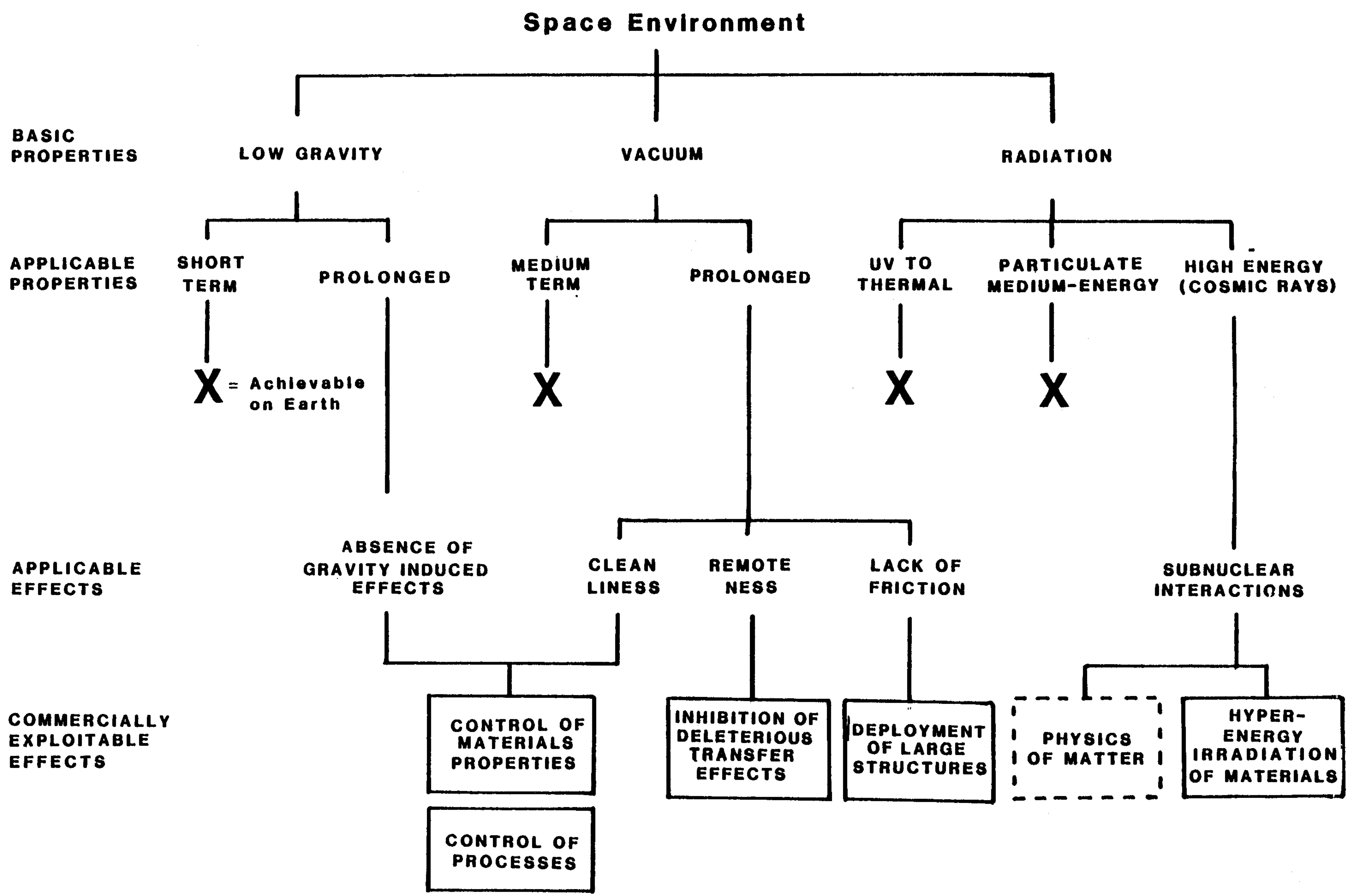


Figure 6 - 1 Unique Properties and Potential Applications of the Space Environment

effect within the spacecraft is cancelled by virtue of the centrifugal force induced by the vehicle's orbital motion. Gravity is completely nullified, however, only at the vehicle's center of mass; it is small but measurable as one moves away from the vehicle's center of mass. In addition, small, spurious forces are caused by orientation maneuvers (or by centrifugal forces due to spacecraft attitude motion if no orientation maneuvers are effected), and by any movements inside the vehicle. These spurious forces cause small departures from ideal zero-g conditions, known as g-jitter.

The presence of gravity gradients and of spurious forces limits the lower level of g forces available within a spacecraft. For this reason, the environment within the spacecraft is termed "micro-g" rather than "zero-g". Table 6-1 illustrates the residual g-levels induced by some of the phenomena which occur within the environment of the spacecraft.

In ideal zero-gravity, the occurrence of important and unique phenomena has been demonstrated. These phenomena have been observed in the low gravity of orbiting spacecraft. For example, deformation due to hydrostatic pressure does not occur. Convection currents, such as movements in fluids due to warmer portions rising and cooler portions sinking, are absent. Fluids do not separate due to density differences, which nullifies sedimentation and eliminates the effects of buoyancy.

Low levels of gravity for short time intervals are achievable using Earth-based methods. The oldest such method is the release of objects from tall structures. Galileo is reputed to have been the first to utilize this method scientifically by dropping objects from the leaning tower of Pisa. During the eighteenth and nineteenth century, "shot towers" were used to cast round lead pellets by dropping molten lead through a sieve onto an underlying tub of water. Famous among these is the Baltimore Shot Tower, built in 1829, which was used through the Civil War and until World War II to produce buckshot. See Figure 6-2.

Because of the drag effect of the air, the free-fall of objects in the atmosphere does not completely simulate absolute zero-g. In addition, drag increases with fall time (and the object's velocity) and, eventually, a constant terminal velocity is reached when drag equals weight, nullifying the initial zero-g conditions altogether.

TABLE 6-1

PRINCIPAL RESIDUAL G-LEVELS PRESENT
WITHIN SPACECRAFT IN LOW EARTH ORBIT (400 KM)

APPROXIMATE FORCES INDUCED BY:	EFFECT, KILOGALS
CONTINUOUS BELLY-DOWN ORIENTATION	$1.33 \times 10^{-7} \times d$
CONTINUOUS INERTIAL ORIENTATION	$3 \times 10^{-7} \times d \sin 2 \frac{t}{T}$
ATMOSPHERIC DRAG	$10^{-3} \frac{A}{W}$
Example: for $A = 100\ m^2$, $W = 100$ tons, $G \approx 10^{-6}$ Kilogals	

d = distance from C.G., meters
T = orbital period, minutes
t = time elapsed, minutes
A = spacecraft frontal area, m^2
W = spacecraft weight, Kg

1 Kilogal $\cong$ 1 g

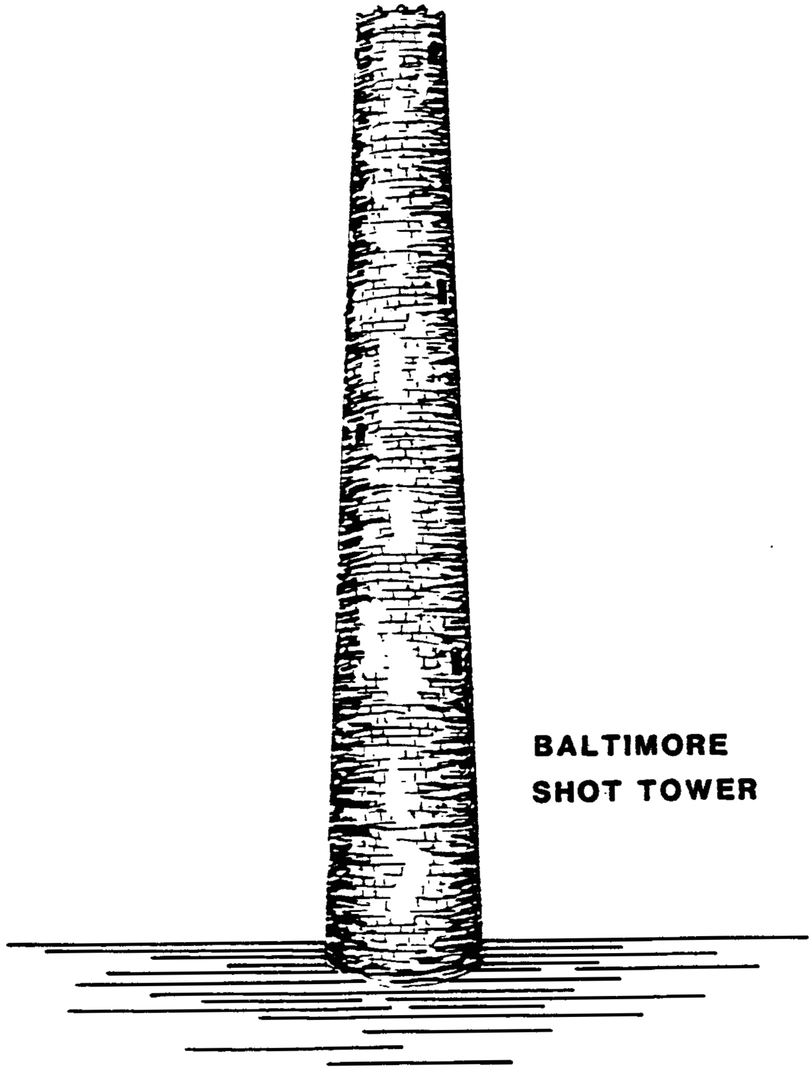


Figure 6-2.

A low gravity production facility built in 1829 and used during the Civil War and up to World War II to produce round shot by dropping molten lead 230 feet onto a vat of water. The molten lead solidified in free fall yielding spherical pellets of the desired caliber.

This problem can be solved by eliminating the atmospheric drag, through use of evacuated drop tubes. The cost of these structures has thus far limited their height. For example, the tallest evacuated tower in existence is that at the Marshall Space Flight Center (MSFC) in Huntsville, Alabama. Its 100 meter height allows free-fall durations of 4.2 seconds. Another method employed to minimize atmospheric drag is the use of an aerodynamic shield, such as the 130 meter drop facility at the Lewis Research Center. Other Earth-bound methods of producing low-g for short periods of time are parabolic trajectories of aircraft and coasting rockets.

All Earth-based methods to date are characterized by short durations of low-g conditions. Low-g environments of short duration can be simulated on Earth at relatively low cost.

This capability is reflected in Figure 6-1, in which the branch of the top-down tree connoting "short-term low-gravity" is terminated at the second level of the top-down chart.

Consideration of long-term effects of low-gravity is pursued at length in Section VIII.

6.3 The Rarefied Medium

The Earth orbital space medium, often designated as a void or vacuum, is not entirely empty. Matter, mostly a plasma, i.e., a gas of charged particles, is present in low densities. Dust, neutral hydrogen, and other chemical molecules are also present in lesser amounts.

The characteristics of the vacuum present in Earth-orbital space are summarized in Figure 6-3. It is apparent that the level of vacuum available at low orbital altitudes is not much higher than what is present in commonplace objects, for example lightbulbs or vacuum tubes (10^{-6} to 10^{-8} Torr).

A significant improvement in the level of vacuum can be attained in the wake of a "shield" moving at orbital velocities. The shield acts as a "sweeper" of the residual particles, as shown in Figure 6-4. The theoretical values of vacuum level, in proximity of such a shield, reach upwards of 10^{-17} Torr.

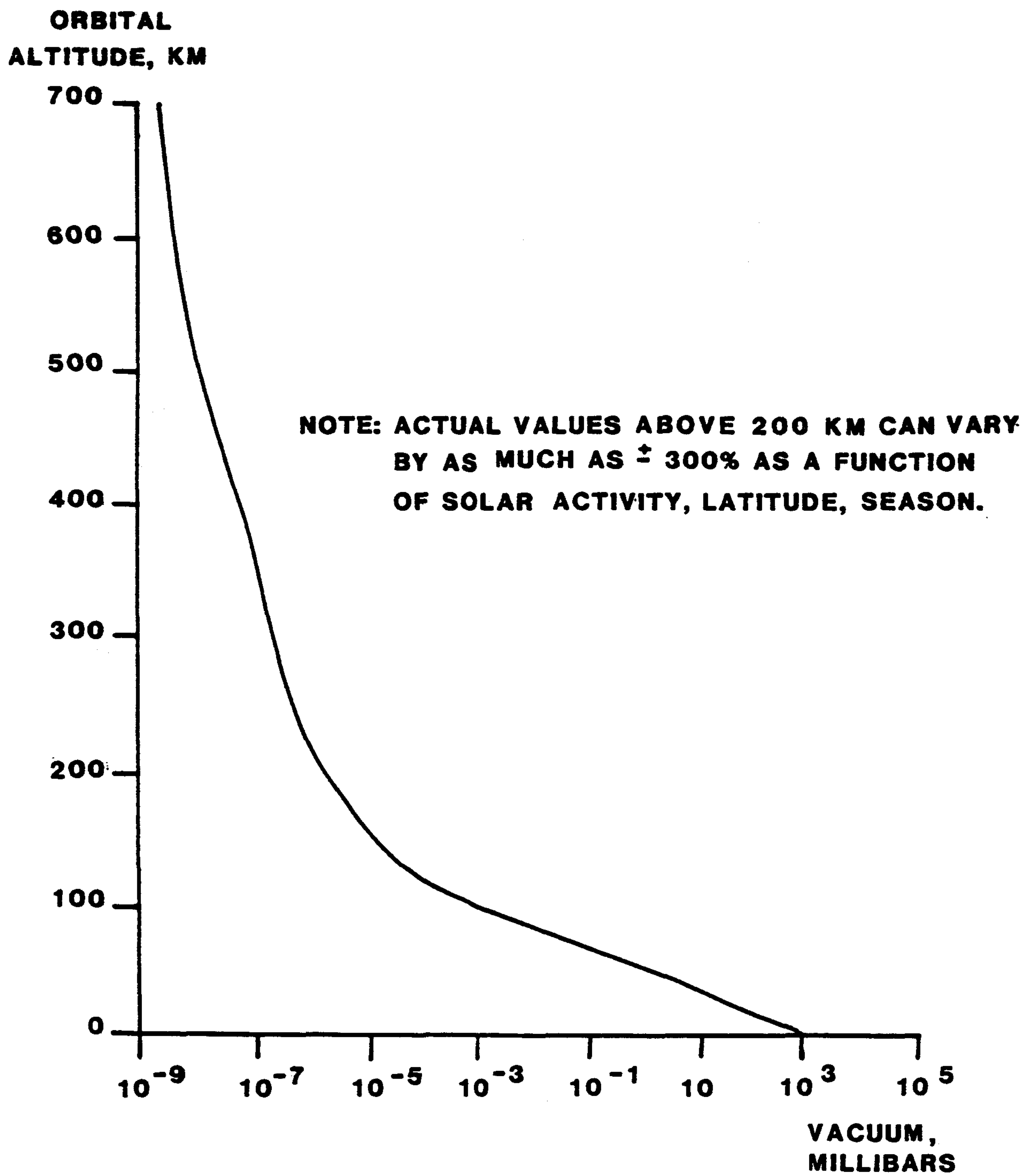
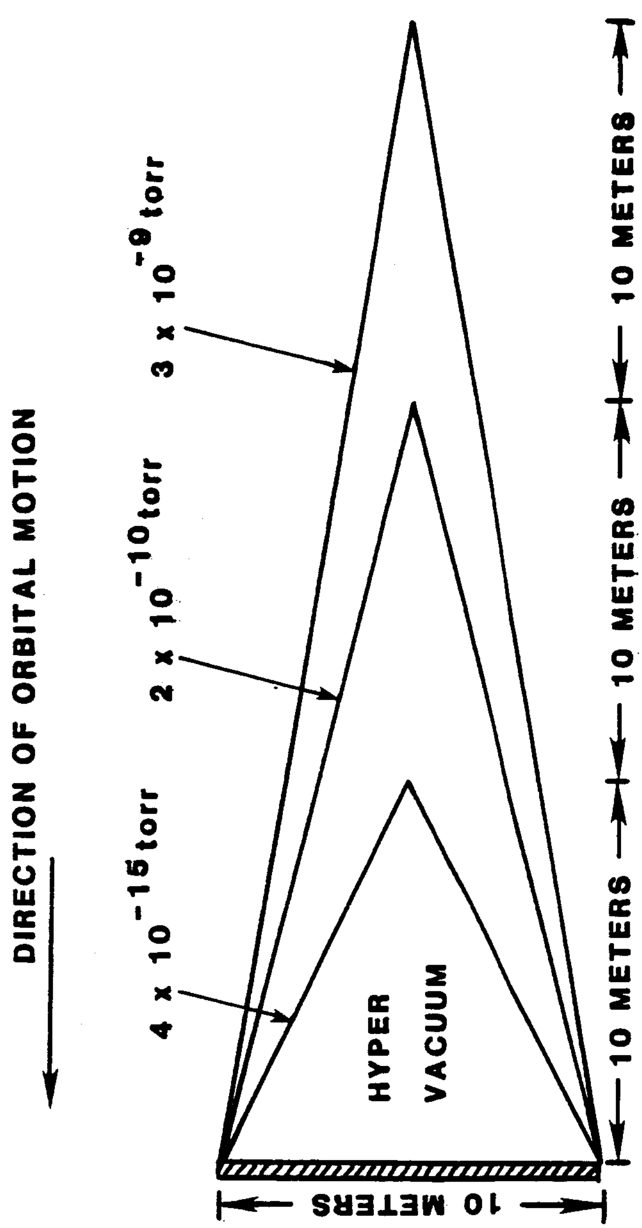


Figure 6-3.
Average Values of Vacuum Available in Earth Orbit.



Vacuum Effect Behind a Moving Shield (Adapted from Naumann, Materials Processing in Space, Nasa SP-443.)

Figure 6-4.

High levels of vacuum, for time spans ranging from hours to days, are achievable in Earth-based vacuum chambers. Thus, in Figure 6-1 the corresponding branch of the top-down tree is terminated: only long duration vacuum is further considered.

With reference to Figure 6-1, three principal exploitable effects of the long duration of a vacuum condition in space are as follows:

- The tendency of unwanted materials to evaporate yields a higher degree of cleanliness or purity among target materials.

- Since continued vacuum, over long distances, is a very good "isolator", the space environment is conducive to preventing deleterious substances from spilling over into the Earth environment. This effect would apply to disease causing or toxic substances, such as pathogens or nuclear debris.

  With respect to nuclear debris, while it is not neutralized by vacuum per se, its attendant energy attenuates, in accordance with the inverse square law, by virtue of the distance between orbital altitudes and the Earth's surface. It is reduced further by the absorbing effect of the atmosphere. Because of this isolating capability of space, the removal of nuclear debris, from the Earth's surface to space, has been advocated in the past. International treaties, however, have prohibited this type of utilization of the space environment.

- The absence of aerodynamic friction permits the deployment and maintenance of large structures, such as antennas for communications purposes.

6.4 Radiation

Space is permeated by a wide spectrum of electromagnetic and particulate radiation. At sufficiently high orbital altitudes, this radiation is present in its pristine form, unimpeded and unabsorbed by the Earth's atmosphere.

In Earth orbit, the principal source of the electromagnetic radiation is the Sun. The solar spectrum, observed above the atmosphere, is shown in Figure 6-5. The Figure also compares the solar exo-atmospheric spectrum with the Sun's spectrum observed at the Earth's surface.

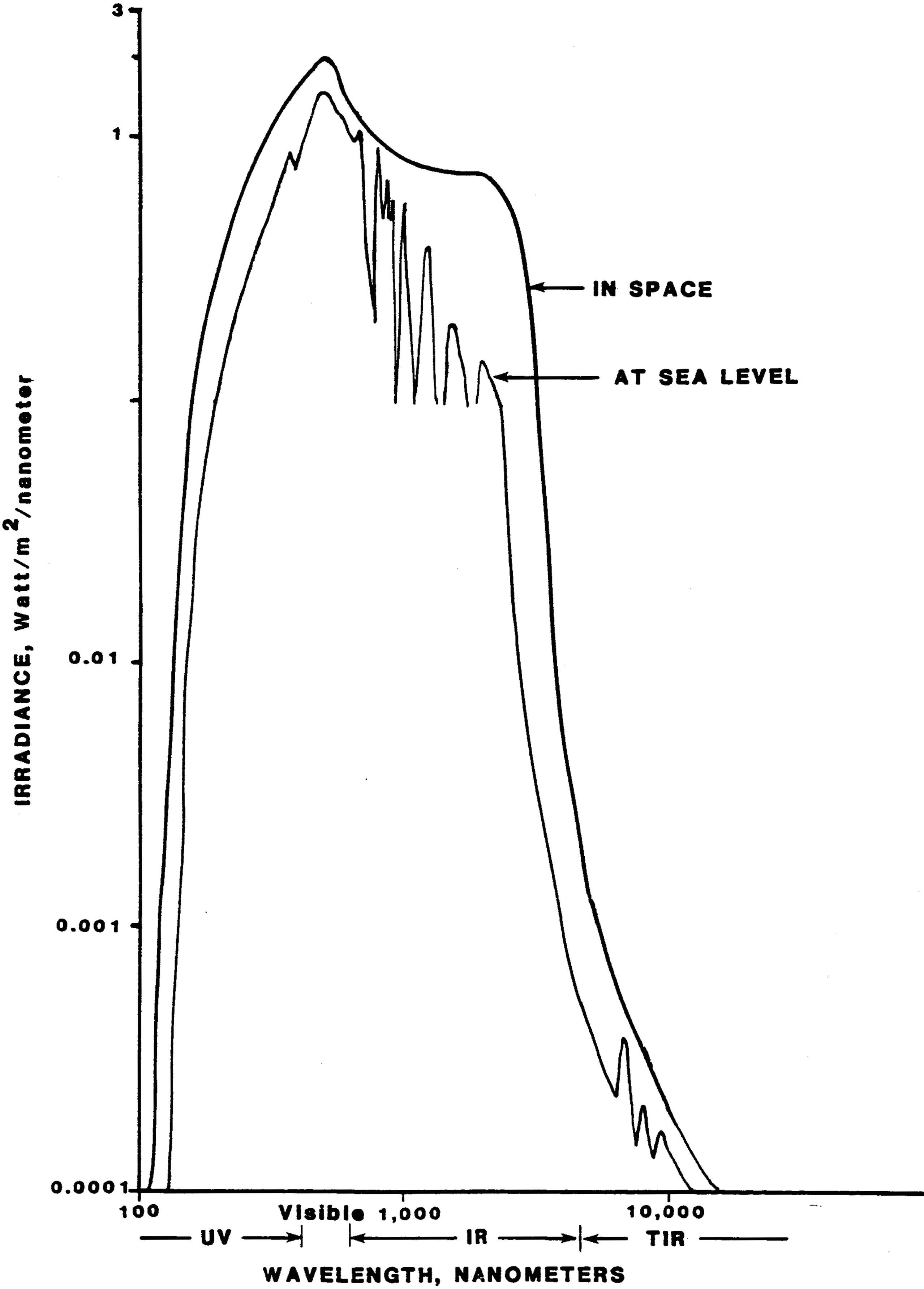


Figure 6-5 Spectral Irradiance of Sunlight

Note that the lower and upper wavelengths of the spectrum, namely the ultraviolet, x-ray, and the thermal infrared portions, are effectively filtered by the Earth's atmosphere. However, these portions of the electromagnetic solar spectrum, which are absent at the Earth's surface, can be simulated on the ground. Thus, the corresponding branch of the top-down tree is terminated in Figure 6-1.

The two principal sources of particulate radiation are the solar wind plasma and cosmic rays.

The solar wind is composed primarily of protons and electrons with ion traces of helium, oxygen, carbon and other elements. The kinetic energies of the particles composing the solar wind are relatively modest, well within the realm of what can be reproduced on Earth. Consequently, the corresponding branch of the top-down tree of Figure 6-1 is terminated.

Cosmic rays, which originate in galactic space, consist of particles (protons and nucleons) possessing energies ranging upwards of 10^8 billion electron volts (Bev). These high-energy particles do not reach the Earth's surface because they "split" and "degenerate" upon colliding with atmospheric molecules. Such high energies, at the present time, cannot be generated even in the best available ground-based particle accelerators. The most energetic of these accelerators is capable of 600 Bev, or several orders of magnitude less than the naturally occurring energetic cosmic rays.

Besides the scientific importance of cosmic rays in cosmological science, such high energy "bullets" are of great significance to physical research. While this physical research is not directly exploitable commercially, its potential future applicability to industry warrants the consideration of a space station as a setting for further research.

An additional potential application of energetic particles is the irradiation of materials. Irradiation is currently being performed industrially in such applications as the conditioning of elastometers and the preservation of foodstuffs. The space environment offers the opportunity of testing the effects of irradiation with hyper-energy particles.

The current status of actual exploration of the space environment for commercial purposes is discussed in the following section.

6.5 Current Status of Exploitation of Space Effects

As was inferred in the previous section, the specific effects of interest to space commercialization are those that are not readily or cost-effectively reproduced on Earth. Thus, those effects, summarized in Figure 6-1, which may be cost-effectively reproduced on Earth, can be readily discounted. The effects of low-gravity can be realized on Earth for periods of a few minutes or shorter; thus, only the free-fall effects of low-gravity in space, lasting for longer periods than are attainable on Earth, are of interest. On Earth vacuums of 10^{-9} to 10^{-12} Torr can be achieved for small volumes for upwards of 1000 hours; in space only vacuums for larger volumes and/or longer durations are worth pursuing. Only extremely high-energy radiation above 600 Bev is currently not produced on Earth; thus, only high-energy cosmic rays are worth considering in space.

Since the beginning of the spaceflight program, various nations, principally the U.S. and U.S.S.R., have attempted to investigate and utilize the unique effects of the space environment shown in Figure 6-1 and discussed above. Table 6-2 summarizes the current status of these efforts.

High-energy cosmic rays have been investigated by the Soviets, circa 1968, through their satellite "Proton", as a means to study the basic physics of matter. As predicted by U.S. scientists, this investigation confirmed the fact that cosmic rays are rare and widely scattered, that is to say few and far between and arriving from random directions. These were indifferent conclusions, not worth the expense of deploying a satellite.

The possibility of using cosmic rays for hyper-energy irradiation of materials has not been explored further.

Isolation and remoteness are useful properties for inhibiting deleterious transfer effects, e.g., pathogenic, and nuclear. As a result, studies have been conducted by NASA to investigate the use of space for the disposal of nuclear materials. These studies have shown that whereas the space environment can be a valid medium for disposal, by jettisoning of materials into the Sun, the corresponding launch costs are excessively high, at least with the current state-of-the-art. Further, the risk of launch aborts and consequent return of the hazardous material to Earth has constituted a major deterrent to this type of utilization of the space environment. Finally, as was previously mentioned, International Treaties do not permit such disposals at this time.

TABLE 6-2

STATUS OF DEVELOPMENT OF COMMERCIALLY EXPLOITABLE EFFECTS OF THE SPACE ENVIRONMENT

APPLICATION	STATUS
• HYPER-ENERGY IRRADIATION OF MATERIALS	• UNEXPLORED
• BASIC PHYSICS OF MATTER	• INVESTIGATED IN SOVIET "PROTON" SATELLITE • RESULTS: LIMITED VALUE DUE TO LOW DENSITY OF COSMIC RAYS
• INHIBITION OF DELETERIOUS TRANSFER EFFECTS	• NUCLEAR WASTE DISPOSAL INVESTIGATED • REJECTED DUE TO HIGH COST AND RISK OF CONTAMINATION FROM LAUNCH ABORTS
• DEPLOYMENT OF LARGE ANTENNA STRUCTURES	• APPROXIMATELY 15 ENGINEERING STUDIES PERFORMED • MARKET ANALYSIS NOT YET PERFORMED • POTENTIAL HIGH COMMERCIAL VALUE TO COMMUNICATION INDUSTRY
• CONTROL OF MATERIALS PROPERTIES AND CONTROL OF MATERIALS PROCESSES	• SUBJECT OF ONGOING MPS PROGRAMS IN U.S., U.S.S.R., EUROPE, JAPAN

The absence of aerodynamic friction is eminently conducive to the deployment and maintenance of space-based electromagnetic relay transceivers. Accordingly, satellite communications is currently a major industry in the U.S. and world-wide. Approximately 36 North-American Domsats are active at this time; 46 are scheduled for deployment by the end of 1984. Approximately 325 communication satellites are forecasted, world-wide, by 2000 A.D. All of these satellites currently utilize relatively small, state-of-the-art antennas. The key question is what commercial benefit could accrue to the U.S. communications industry (currently grossing a yearly total of $100 billion) from the ability to add large antennas to these communication satellites. Approximately fifteen studies have been conducted by NASA on the engineering of large antenna structures. No analyses have been performed, however, regarding their potential commercial utility.

The use of the space environment for MPS, which is the principal subject of this report, is currently being pursued by NASA, the European Space Agency, the U.S.S.R. and Japan.

VII. TEST FACILITIES

7.0 Concept

As discussed in the previous section, the current commercially exploitable effects of the space environment are low gravity, vacuum or a combination of these.

Low gravity can be simulated on Earth for limited periods of time through several techniques. The simplest method is to drop objects from elevated structures as was done in the past from "shot towers" — or as is currently being done in evacuated drop facilities. Also, aircraft in parabolic trajectories or SPAR rockets during their coasting phase generate low gravity conditions for limited time periods.

Because these low-g conditions are for short durations only, the processing of materials in such brief periods must be at a scale in which the low-g conditions can effectively influence the material. Table 7-1 verifies this by depicting typical sizes of materials which can be processed under these conditions, namely small samples.

For larger samples the duration of exposure to low-g is the characteristic of highest potential interest to industry.

By an analogous reasoning, the key characteristics of vacuum processing are the level of vacuum and of the temporal exposure to this level of vacuum.

7.1 Low Gravity

Several means are available for producing low gravity, short of utilizing an orbiting space vehicle. In MSFC's 30 meter drop tower, gravities as low as 10^{-5} g can be sustained for 2.4 seconds; in the 100 meter drop tower, similar gravity levels can be sustained for 4.2 seconds. In the Lewis drop facility, 5 seconds at 10^{-5} g are possible. Aircraft in parabolic trajectories can produce low gravity of 10^{-1} g for 40 seconds or 10^{-2} g for perhaps 10 seconds. Rockets can produce a gravity of 10^{-4} g for upwards of 4 minutes. The curve labeled "Earth" in Figure 7-1 represents the envelope of these values.

TABLE 7-1

TYPICAL SIZES OF MATERIALS SAMPLES WHICH CAN BE PROCESSED IN GROUND-BASED LOW-GRAVITY FACILITIES

FACILITY	LOW-g TIME SECONDS	SAMPLE SIZE GRAMS
30-METER DROP TUBE	2.4	0.5 TO 1
100-METER DROP TOWER	4.2	1 TO 5
AIRCRAFT	10 TO 60	5 TO 10
ROCKET	240 - 360	200 TO 300

Source: Commercial Applications Office, Marshall Space Flight Center

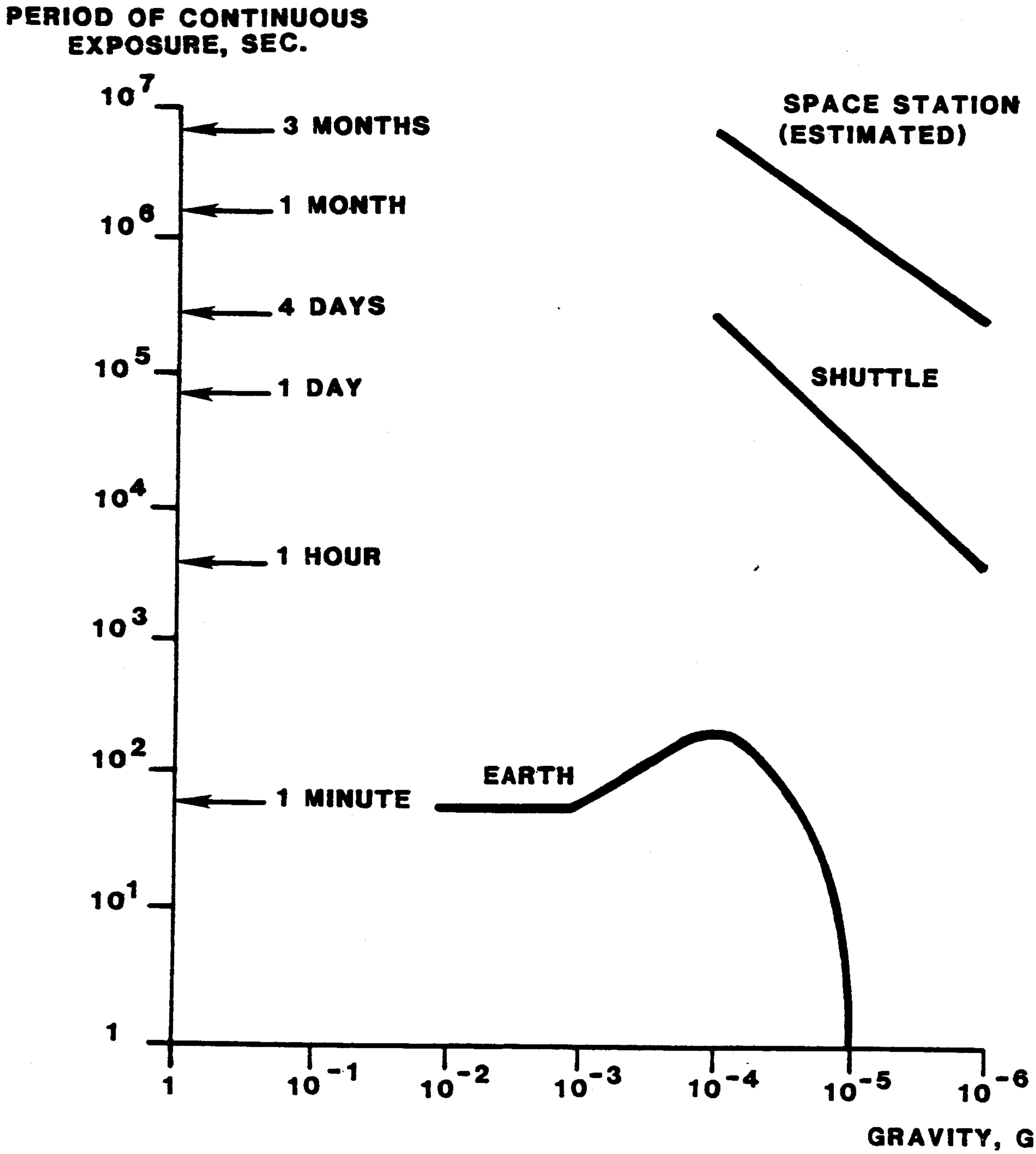


Figure 7-1.
Profile of Best Attainable Microgravity x Duration Levels.

The Shuttle, limited by its mission capabilites, can produce continuous gravity levels slightly less than 10^{-4} g for a maximum of four days. It can generate lower gravities (10^{-6} g) for shorter periods (order of 1 hour) with the help of special operational procedures. The estimated g-time duration Shuttle envelope is shown in Figure 7-1.

In theory, a space station could maintain continuous low gravity of at least 10^{-4} g for several months. Lower gravity levels of order 10^{-6} g could be achieved for shorter periods given the use of special operational procedures and a suitable location of the experimental equipment. The corresponding estimated space station g-time duration envelope is shown in Figure 7-1.

7.2 Vacuum

The technology for generating vacuum is well developed on Earth. Pumping devices used to evacuate lightbulbs and vacuum tubes maintain a vacuum of 10^{-6} to 10^{-8} Torr for periods of time as long as 1,000 hours. High-technology vacuum pumps can produce a vacuum of 10^{-16} Torr for up to one hour, see the curve labeled "Earth" in Figure 7-2.

The Shuttle, because of its low orbiting altitude, can produce vacuums not greater than approximately 10^{-7} — 10^{-8} Torr for up to 4 days (duration of a typical Space Shuttle mission).

Greater vacuums are obtainable at higher altitudes and/or in a Space Station equipped with special devices such as the Wake Shield, see Figure 6-4. By virtue of its longer mission and possibly higher orbital altitudes, the Space Station is estimated to be able to produce vacuums of 10^{-9} Torr for periods of 10,000 hours or more. Fitted with a Wake Shield, The Space Station should be able in theory to provide and maintain a vacuum of 10^{-16} Torr for upwards of 1,000 hours.

7.3 Combination of Gravity and Vacuum

On Earth, it is difficult to produce the two effects concurrently for an appreciable length of time. The best obtainable non-orbiting facility is a coasting rocket, maintaining both low gravity (10^{-4} g for four minutes) and vacuum of up to 10^{-4} Torr, depending upon the altitude reached.

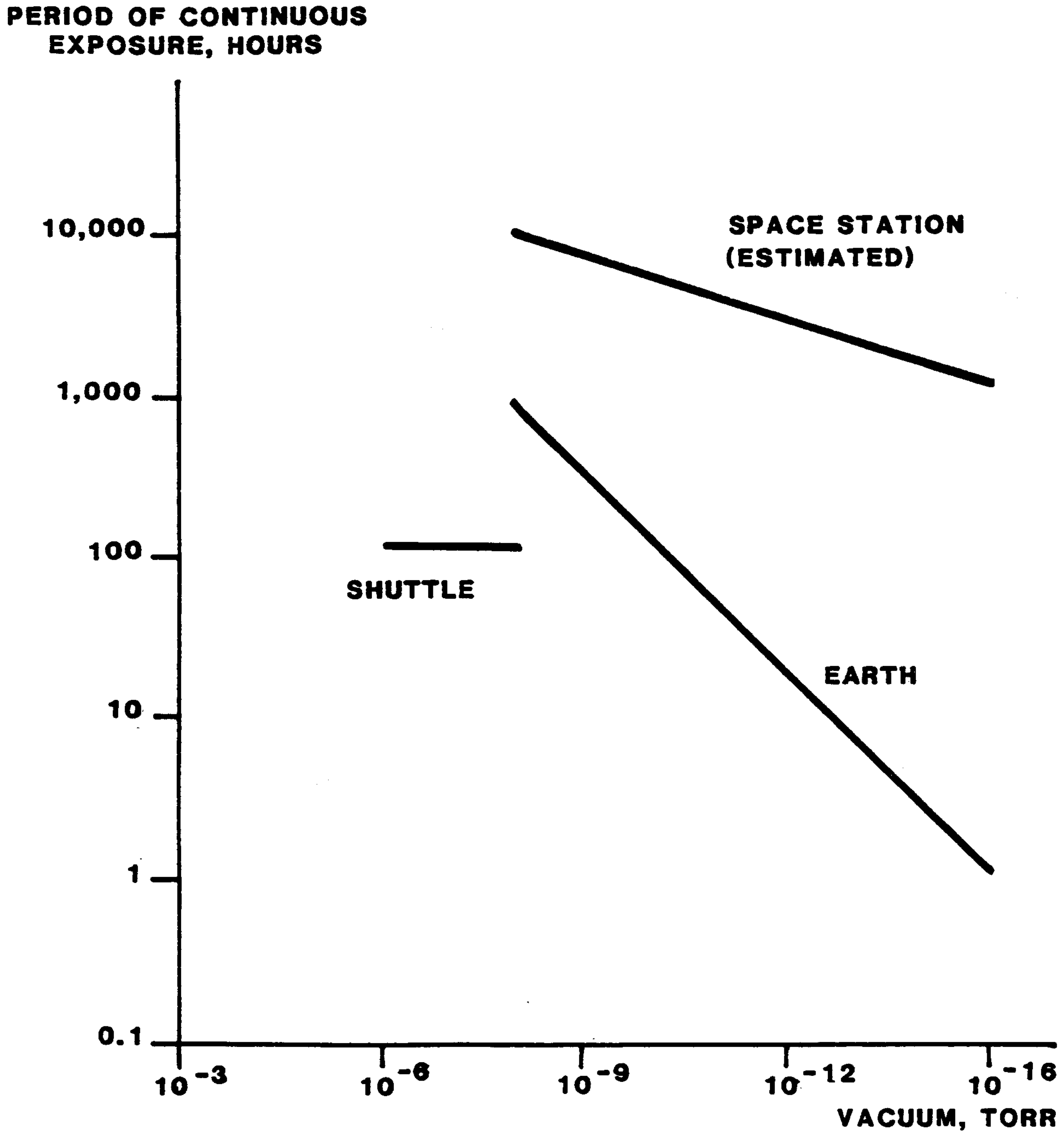


Figure 7-2.

Profile of Best Attainable Vacuum x Duration Levels.

The advantage to be gained from producing combinations of low gravity and vacuum in space is in terms of the length of time in which both can be sustained simultaneously. Estimated gravity-vacuum envelopes for both Shuttle and Space Station are shown in Figure 7-3.

7.4 The Figure of Merit Concept

The previous discussion leads to the desirability of defining a figure of merit reflecting the quality of available low gravity and vacuum. The formulation of a proposed figure of merit is shown in Table 7-2. The proposed figure of merit is designed to increase as the effect-duration product becomes larger. Since the quality of the effects -- gravity and vacuum -- increases in inverse proportion to their magnitudes, it becomes natural to place the measure of the effects in the denominator. The combination of both is expressed as the "intersection" of the individual figures of merit for gravity and vacuum, i.e., the duration of simultaneous exposure to low gravity and vacuum.

Table 7-3 depicts computed and estimated figures of merit for various effects and facilities. The numbers presented show the great superiority of the space medium for using either/or both vacuum and low gravity. The Space Station, with a potential for long-term space missions, ranks highest among the facilities.

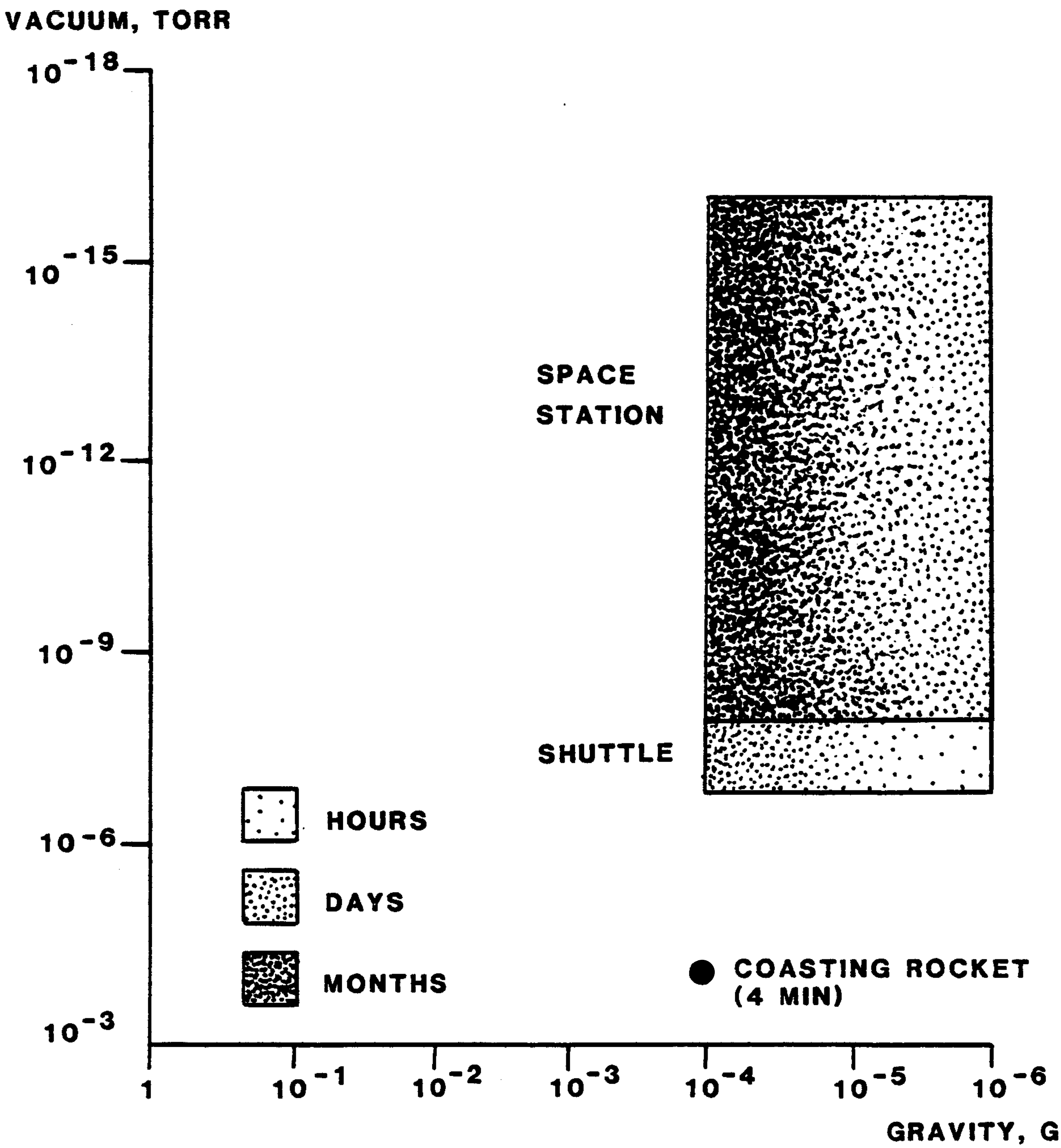


Figure 7-3.

Attainable G-Vacuum - Duration Envelopes.

TABLE 7-2

PROPOSED FIGURES OF MERIT FOR
LOW G AND VACUUM

EXPOSURE TO LOW-G:

$$Fg = \frac{\text{Duration of Exposure, Sec}}{\text{G-Level, Milligals}}$$

EXPOSURE TO VACUUM:

$$Fv = \frac{\text{Duration Of Exposure, Hours}}{\text{Vacuum Level, Pico Torr}}$$

COMBINED EXPOSURE:

$$Fgv = Fg\ \Omega\ Fv$$

Ω = "topological" intersection = duration of simultaneous exposure to low g and vacuum.

TABLE 7-3

COMPARATIVE
FIGURES OF MERIT OF AVAILABLE AND
PLANNED MPS FACILITIES

FACILITY	Fg	Fv	Fgv
AIRCRAFT	0.005	≈ 0	≈ 0
COASTING ROCKET	3	≈ 0	≈ 0
DROP TOWER	0.3	≈ 0	≈ 0
GROUND-BASED VACUUM CHAMBER	N.A.	UP TO 10^4	0
SHUTTLE	3,500	UP TO 0.1	
SPACE STATION (EST.)	UP TO 300,000	UP TO 10^8	

VIII. SYNTHESIS OF MPS APPLICATIONS

8.1 Categorization of MPS Applications

A categorization of MPS Applications has developed piecemeal over the last decade and a half. It grew as new applications were devised, gradually developed, and added to the inventory of actual or potential usages of MPS. The current categorization of MPS applications is listed in Table 8-1.

While perfectly adequate and comprehensible to scientists and engineers familiar with the field, this conventional categorization of MPS applications presents some difficulties when submitted to industrial R&D managers not already conversant with MPS lore. One of its problems is that it intermixes products, processing techniques and apparatus.

For example, the term "containerless processing" in Table 8-1 connotes a technique rather than a product. The term evinces, at first blush, exciting vistas of unique and valuable capabilities. Upon further consideration, however, the industrial representative is unavoidably forced to ask himself "how does containerless processing relate to my specific processes or products?"

The answer is not easily obtained: it requires a considerable depth of analysis for which the required time is seldom available to the busy industrial manager.

Similarly, the category "crystal growth and solidification" connotes a set of techniques — the utilization of which is obviously not unique to the space environment — that are common to the manufacture of diverse products, e.g., semiconductors, special optical substances. The recipient needs to engage in the mental process of assessing how this technique, when effected in space, does differ advantageously from conventional methods of growing crystals.

A more succinct grouping of the categories shown in Table 8-1 has recently appeared in the literature, see Table 8-2. While it has the virtue of conciseness, this abbreviated grouping still presents a problem for the industrial user, namely relating MPS categories to specific industrial products or processes.

TABLE 8-1

CONVENTIONAL CATEGORIZATION OF MPS APPLICATIONS

- Crystal Growth and Solidification
- Electrokinetic Separation
- Fluid Mechanics
- Composites
- Suspensions
- Immiscible Systems
- Solidification Front Interactions
- Monodispersed Latex Spheres
- Critical Phase Transformations
- Floating Zones
- Distortional Influences
- Containerless Processing
- Degassing and Desorption
- Extensive Electron Beam Processing

TABLE 8-2

ABBREVIATED CONVENTIONAL CATEGORIZATION OF MPS APPLICATIONS

- Crystal growth
- Solidification of Metals, Alloys and Composites
- Fluids, Transports, and Chemical Processes
- Ultra High Vacuum and Containerless Processing Technologies

The above observations, derived from interfacing with R&D managers of potential MPS user industries, indicate the desirability of developing a categorization scheme suitable for facile communication with commercial users and capable of providing a visible and useful synthesis of the functions which the space environment offers to the field of materials processing. See Sections X and XI for details on discussions with R&D managers of potential MPS user industries.

8.1 Alternate Categorizations

As is the case with all new sciences, the young lore of MPS has grown during its short lifetime through an inductive process. Diverse findings and ideas accreted to the body of MPS knowledge as they gradually emerged.

The natural evolution of a maturing science is the eventual transition from the inductive to the deductive approach to knowledge, i.e., from the particular to the general, from a collection of facts to the definition of underlying and unifying "laws".

The advantage of the deductive approach is that it permits the philosophically satisfying process of explaining the available facts; further, and more useful in practice, it allows the prediction of the ultimate consequences of "laws" and thus serves to guide subsequent research towards approaching the ultimate limits of which the technology is capable.

At this time, MPS appears to be sufficiently mature to lend itself to such a process of deductive categorization.

A deductive categorization of MPS functions should begin with principles, i.e., with the ultimate objectives of MPS; it should progress subsequently to its applications, through an analysis of the exploitable properties of the space environment, following an ordered sequence of logical steps.

The end applications derived from this approach should satisfy five criteria:

- Orthogonality, i.e., the applications should not overlap each other

- Comprehensiveness, i.e., the method should encompass the spectrum of current and potential future applications

- Traceability, i.e., the genealogy of each application should be unequivocally relatable to the objectives through each step of the logic

- Visibility, i.e., the logic should allow facile communication and understanding on the part of recipients not fully conversant with the field

- Significance, i.e., the end results should be expressible in terms related to economic value

Figure 8-1 illustrates a scheme of classifications derived from the top-down approach introduced in Section 6, see Figure 6-1.

As can be seen by comparing Figure 8-1 with Table 8-1, this scheme reconciles the current categorization with a deductive classification. The scheme represents a science-oriented approach, useful to technologists for categorizing actual or potential MPS products in terms of the space environmental effect, or a combination of effects, utilized to generate them.

A more industrially-oriented categorization is depicted in Figure 8-2. Its logic derives from two top-level objectives:

- The development of materials having specified characteristics

- The development of material-producing processes which are economically worthwhile, i.e., efficient in terms of the required resources

These two objectives have been the goal and have permeated the evolution of materials processing throughout mankind's history.

In pursuit of the first objective, for example, stone implements have been gradually replaced by bronze, iron and then steel; bark bowls have given way to earthenware, porcelain, and plastics; medicinal herbs have been superseded by potions, inorganic pharmaceuticals and finally antibiotics. In all cases, new developments in materials

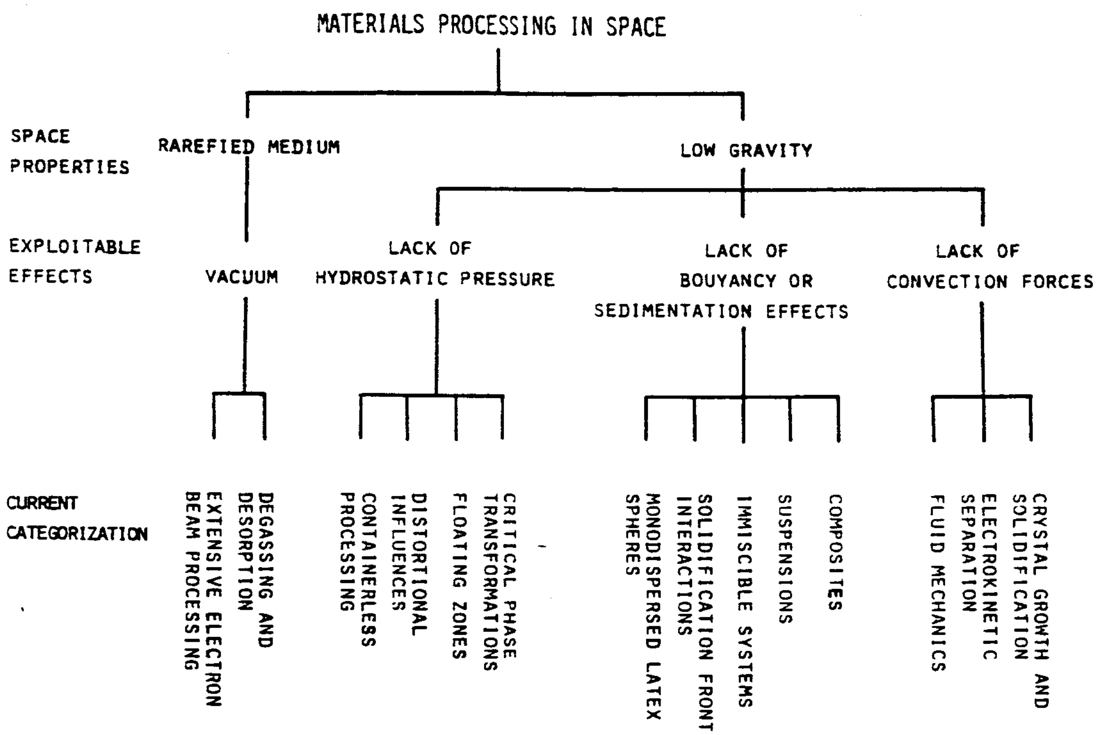


Figure 8-1. Reconciliation of Current Categorizations of MPS Applications with Top-Down Approach

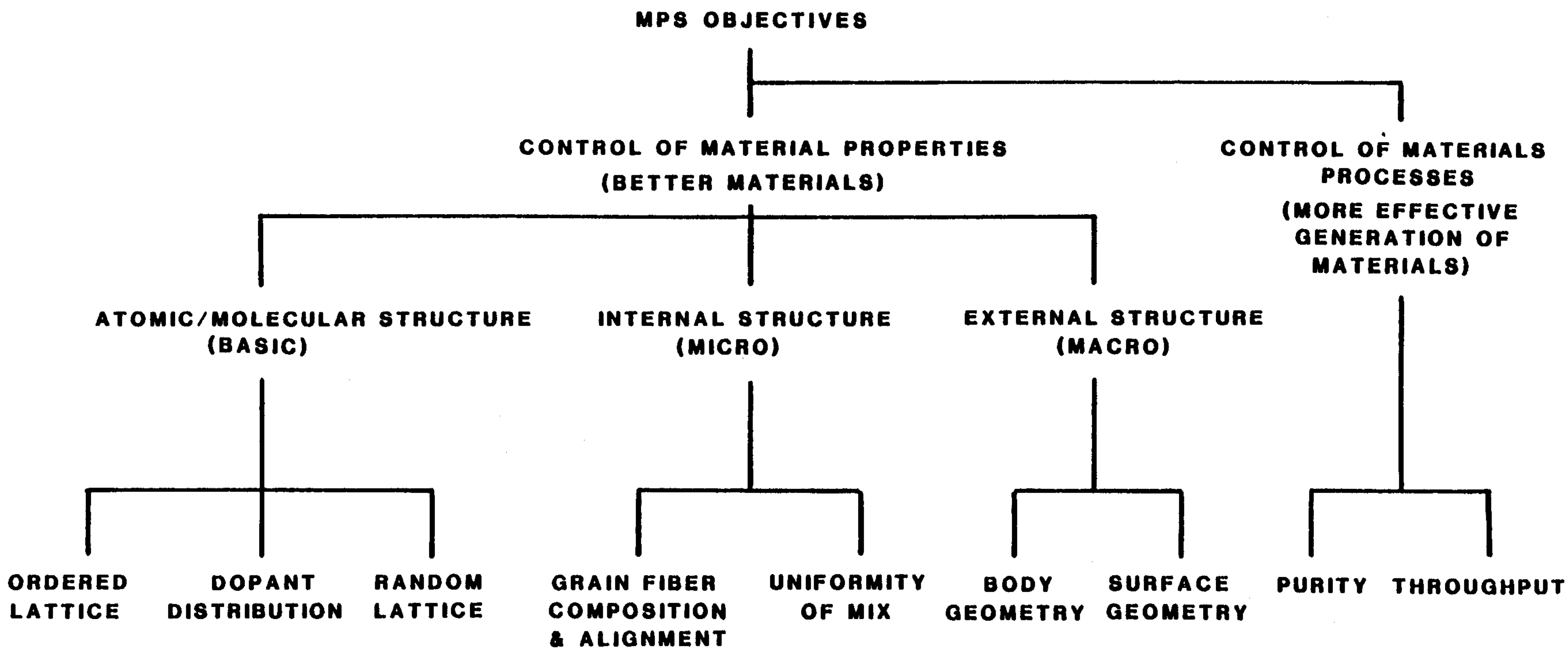


Figure 8-2. Materials Processing in Space – Categorization by Objectives

technology have evolved through improved understanding of how to control the properties of the corresponding substances.

The second objective listed above addresses the obvious requirement for economic efficiency. The occasional lumps of iron produced in Sumerian copper smelters became of practical use only after the Hittites discovered how to produce the metal at sufficiently low cost to warrant replacing their army's bronze swords. Aluminum, worth more than gold before the inception of this century, became a major element of modern technology only after the economical process of cryolite electrolysis was developed.

The two objectives stated above correspond to the two top-level branches shown in the logic tree of Figure 8-2, labeled respectively: Control of Materials Properties and Control of Materials Processes.

Modern materials technology seeks to control the properties of materials at three levels:

- The atomic or molecular structure — Control of materials properties at this level represents the highest degree possible for practical control to date.* Such structural control is ultimately desirable for most materials. However, because of its difficulty and expense, it is currently exercised for products only where its use is of paramount necessity.

  Control at the molecular level is required: 1) for generating highly ordered lattices used, for example, as building substrata for semiconductors; 2) for achieving distributions of suitable "impurities" (dopants) in exact proportions and at precisely determined locations within ordered lattices in order to produce high-quality semiconductors; or 3) for accomplishing highly random distributions of atoms and molecules, needed for producing the category of materials conventionally known as "glasses".

- Internal macromolecular structure — Control at this level involves the distribution or alignment of groups of molecules. This type of control is

* Control at the subatomic level is a logical next step of the advancing MPS technology. It has not as yet appeared in current literature.

attempted in the metallurgical industry, for example, to achieve desired proportions and spatial distributions of hard perlite grains within softer iron-carbon matrices. Concentration of hard grains at the surface of the internal parts of machines provides resistance to wear; the softer material throughout the rest of the machine provides resilience to impact. Also, grain and fiber control is used to achieve uniform or pre-assigned distributions of two or more materials, each having specified grain sizes which are immiscible in bulk.

- External structure — Control at this level defines the shape of macroscale objects. The intent of this type of control is to provide exact geometrical shapes — e.g., perfect spheres — and/or preassigned surface finishes. Examples are ball bearings, microspheres, electrical contacts.

It is clear that the three levels of control defined above can be attained jointly.

For example, machine parts almost always couple controlled internal grain structure with precise external dimensions. Such combinations are conventionally achieved by serial processing. One of the exciting promises of MPS is the possibility of its accomplishment by means of a single processing operation — for example, through containerless processing.

In addition to striving for control of materials properties, modern industrial technology seeks to continuously improve the economics of materials processes. This important facet of MPS is indicated by the right-hand branch of the logic tree of Figure 8-2.

MPS technology offers two opportunities for improving processes:

- Manufacturing in the space environment, and

- Experimenting in the space environment

The first opportunity applies to situations where the value of the end-product is sufficiently high, and the improvement of processing efficiency is sufficiently significant to more than offset the transportation costs to and from space. The second opportunity applies in cases where three driving factors are present: 1) conventional terrestrial manufacturing processes are not clearly understood; 2) improved understanding can lead to significant reduction in the costs of the product; and 3) the sales of the products are sufficiently conspicuous so that even modest savings in processing costs would more than offset the expense of space experimentation.

The classification proposed and shown in Figure 8-2 appears to meet the criteria of usefulness outlined previously. The classification scheme is orthogonal; there is no overlap among functions. The classification is comprehensive because all classes of materials, e.g., glasses, semiconductors, ceramics, metals, composites, polymers and complex biochemicals, fit into one or more of the control schemes. Traceability is preserved because each material can be connected to a specific class of control and related back to the objectives of MPS.

In the writer's experience, this type of categorization, by virtue of its orientation towards "what to do", serves to focus the industrial manager's perception onto the MPS application of particular interest to his concern.

Note that the proposed categorization eliminates items which connote techniques or apparatus, e.g., "containerless processing". The latter fall within the realm of "how to do" rather than "what to do". They belong in a subsequent phase of MPS consideration, dealing with which specific choice of technique to employ in attempting to achieve the industrial customer's materials control objective.

8.2 Commercialization — Oriented Results of MPS Program to Date

The time span of available results is from 1968 to 1980, therefore, results from the Space Shuttle flights are not included. Prior to the Space Shuttle, approximately 130 MPS-oriented experiments and tests were conducted by the U.S. for a total of approximately 30 hours of low-g exposure. These experiments and tests are summarized in Appendix A. The summary was derived from existing published literature. For each investigation, the summary in Appendix A provides the following information:

- Title of the Investigation as assigned in the literature

- Name and organization of the Principal Investigator (PI)

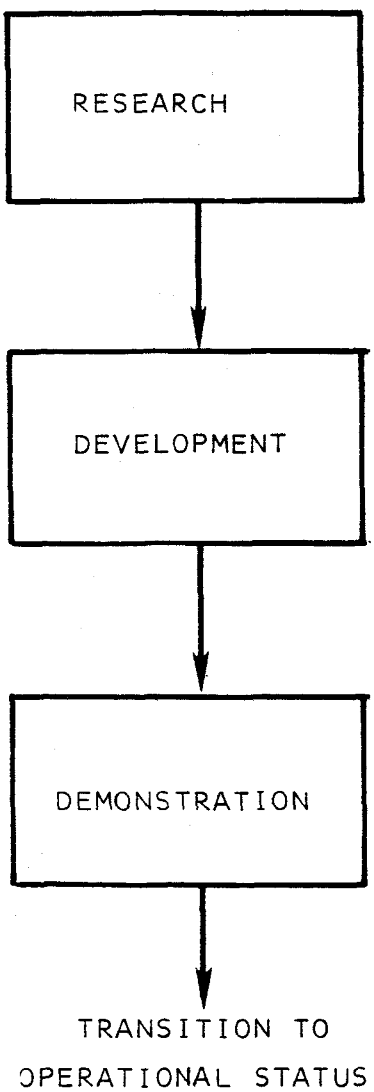
- Vehicle on which the investigation was conducted, e.g., ground, rocket, Skylab
- Time frame when the investigation was conducted
- Objective of the investigation
- Results accomplished

Note that the column labeled "results" in Appendix A is filled for approximately 50% of the investigations. The modest number of these results is common to other PI programs performed in the past, and it is understandable from the fact that scientists are frequently reluctant to qualify the mere achievement of progress as a result.

For purposes of commercialization, it is important, however, to somehow leapfrog the pace of progress. This can be accomplished by inferring expected or potential results from the investigations to the extent that such inferences are warranted by the investigation's scientific content or demonstrable promise. A methodology for extrapolating results from investigation reports is shown in Section 8.4 and is tested on a sample basis in Section 8.5.

Of significance to the overall MPS program is the current status of the investigations, in terms of progress through the successive steps of research, development and demonstration. The scheme of categorization is shown in Figure 8-3. With reference to the Figure, note that the goal of research is to define, modify and verify a concept which holds promise for MPS. The objective of development is both descriptive and predictive, resulting in the verification of a concept suitable for commercial demonstrations or suggesting new approaches for research to modify the concept. The purpose of commercial demonstration is to show that the processing concept works on a larger scale, that processing is economically attractive and that the market exists for the corresponding product.

The investigations listed in Appendix A were categorized as to the stage of progress toward commercialization and are presented in Figure 8-4. Note that only two experiments could be classified as pilot-scale demonstrations. The one listed in the



- CONCEPT DEFINITION
- THEORETICAL MODELING
- EXPERIMENT DESIGN
- EXPERIMENTAL VERIFICATION ON GROUND

- DESIGN OF TEST APPARATUS
- REPLICABLE EXPERIMENTATION TO VALIDATE APPLICABILITY TO SPACE PROCESSING
- EXPERIMENTAL APPLICATION OF THEORY TO DEMONSTRATE PREDICTABILITY OF RESULTS ACROSS RANGE OF CONDITIONS/MATERIALS

- DESIGN OF PILOT UNIT
- OPERATION OF PILOT UNIT
- ECONOMIC ANALYSIS TO VERIFY COMMERCIAL POTENTIAL
- MARKET STIMULATION

Figure 8-3. Stages of Progress Towards Commercialization

		RESEARCH	DEVELOPMENT		DEMONSTRATION	
			EXPERIM. DATA	EXPERIM. APPARATUS	PILOT DEMO	PROCESSING APPARATUS
LOW GRAVITY	ABSENCE OF HYDROSTATIC PRESSURE	23	7	5	-	2
	ABSENCE OF CONVECTION	33	19	-	1	2
	ABSENCE OF BOUYANCY/ SEDIMENTA-TION	27	15	-	1	
RAREFIED MEDIUM	VACUUM	3	-	-	-	

Figure 8-4. MPS Experimentation Categorized by Stage of Progress Towards Commercialization

(Through September 1982)

column "absence of convection" demonstrated free-flow electrophoresis. The other listed in the column "absence of buoyancy-sedimentation" demonstrated the manufacture of large monodispersed latex spheres.

Comparison of the "categorization by objective" of Figure 8-2, and the "categorization as to progress" of Figure 8-4, leads to a broad hypothetical inference relative to potential commercialization of MPS materials. Electrophoresis, which appears closest to commercialization in Figure 8-4 (under the heading "absence of convection" and "pilot demo"), fits under the right-most column "control of material processes" of Figure 8-2. The microsphere experiment, also close to commercialization (see Figure 8-4 under the headings "absence of buoyancy sedimentation" and "pilot demo"), fits in Figure 8-2 within "body geometry" under "external structure". Both these categories connote control of materials properties on the largest (macro) scale. Experience thus appears to indicate that control is most difficult for the smaller scales, less difficult as the scale of the product increases. It could be hypothesized that product candidates for commercialization will likely reach fruition in those applications requiring control of the macroscopic structure of a material or process.

Almost two-thirds of the investigations tabulated in Figure 8-4 lie in the research category. For most of these, the Principal Investigators did not provide explicit results. As indicated previously, a suitable methodology can be used for inferring results.

8.3 Methodology for Synthesis of Results

The methodology follows the approach outline below.

Step A. The MPS investigations are subdivided by categories following the approach presented in Figure 8-3. Analysis of the approximately 130 investigations summarized in Appendix A indicates that they fall into four categories in descending order of achievement of "hard" results:

1) Demonstrations of processes. These are tests, or series of tests, aimed at defining the technical and economic characteristics of specific MPS processes and/or products; for example, the series of electrophoresis processing tests performed on the Space Shuttle;

2) Experimental data points collected in a low-gravity (and/or vacuum) facility. In this category fall experiments aimed at demonstrating specific effects of the space environment, postulated by theory; for example, Skylab tests to validate the fact that convection does not operate under weightless conditions;

3) Theoretical analyses — for example, the extensive series of researches performed by the Bureau of Standards under contract to NASA;

4) Process technology or equipment developments necessary to enable precise measurements or collection of data unique to the space environment. These include special studies and techniques for the transfer of processes to Earth-based systems.

Step B. For each category of investigation defined above, the corresponding report material is analyzed to determine which of the following elements of information have been yielded by each investigation:

1) Results indicating a major technical and a promising economic advantage of processing in the space environment;

2) Results indicating an experimentally proven advantage of the space environment;

3) Results indicating a definite theoretical advantage of the space environment;

4) Inconclusive results observed, despite an apparently correct experimental procedure;

5) Inconclusive results due to a faulty experimental procedure. Typical of this case is the documented occurrence, or the

suspicion of occurrence, of spurious spacecraft maneuvers which have interfered with an experiment. An example is the "sphere forming" low-gravity experiment in Skylab;

6) Definitively negative results. This would imply that the hypothesis postulated for the investigation has unquestionably been proven faulty. Note that very few, if any available experimental findings are expected to fall into this category;

7) Results not available or proprietary

Step C. For each of the above categories (A) and elements of information (B), the reported "positive" and "promising" results, i.e., those corresponding to items B1, B2, B3 above, were extrapolated, consistent with scientific correctness, to indicate the "expected potential" from the particular techniques used in the investigation under analysis.

Step D. The positive and promising results — whether extrapolated from theory, or from experimental data points, or from process tests — are integrated with results currently available from the Marshall Space Flight Center, and with results solicited from other NASA Centers.

Step E. The results were compiled and analyzed. A matrix of the breakdown of all 133 experiments into the four categories and seven yield areas mentioned above is included in Table 8-5.

8.4 Initial Test of the Methodology for Synthesis of Results

To provide an example of the operation of the methodology, six investigations, among the 133 reported in Appendix A, were selected and categorized according to the methodology established above. The criteria for choosing these experiments were: (1) the original literature versions of these experiments had already indicated "results", albeit expressed in scientific terms rather than in commercially oriented format. This made the application of the methodology more straightforward than if no results at all had been indicated; (2) these investigations fell in categories B1, B2, and B3 as defined in the previous Section, i.e., they could be classified as "positive" or "promising"; (3) investigation reports were supported by additional documentation, allowing ancillary confirmation of the extrapolations performed.

The six investigations thus selected are summarized in Table 8-3. Note the difference between the contents of the column labeled "Extrapolated Results" in Table 8-3 and those in the column labeled "Results" in the corresponding investigations presented in Appendix A.

The last column of Table 8-3, labeled "Criterion #", refers to the specific step of progress indicated in the methodology outlined in the preceding Section.

The inferred commercialization potentials, corresponding to the six investigations exemplified in Table 8-3, are listed in Table 8-4.

8.5 MPS Statistics

Table 8-5 displays the breakdown of experiments and results. From this Table, two very distinct observations can be made: 1) The lack of results indicating "major technical and promising economic advantage"; 2) an abundance (45.8 percent) of experiments devoid of available result data.

As a rule, experiment results are formulated in a technical terminology not readily understandable to potential industrial users. Although experiment objectives are established to prove the advantage of utilizing the space environment, the economic advantage of results is beyond the scope of the objectives. Therefore, none of the experiments show up in yield area one.

The abundance of unavailable experiment results is due to two factors -- the ongoing nature of several experiments and the lack of a centralized source of MPS program results. The latter is discussed in Section V, "Data Sources." When results do become available, it is likely that a majority of the experiments in yield area seven will fall under categories two or three.

TABLE 8-3

EXAMPLES OF RESULTS RELATIVE TO COMMERCIALIZATION

CODE	TITLE	INVESTIGATOR ORGANIZATION SPONSOR	VEHICLE	TIME FRAME	OBJECTIVE	EXTRAPOLATED RESULTS	CRITERION #
76	Zero-G Processing of Magnets	Dr. D.J. Larson Grumman Aerospace Corporation	Apollo-Soyuz		To investigate the effects of reduction of gravitationally dependent elemental segregation and convection in the solidification of high-coercive-strength magnetic composites in low-g.	MnBi rods made in space were finer and more evenly distributed in the B_i matrix than ground samples. The low-temperature coercive strength of this magnet was among the strongest ever measured.	B.3
80	Electrophoresis Technology	Dr. R.E.Allen MSCF Dr. G.H.Barlow Abbot Labs	Apollo-Soyuz		To demonstrate the feasibility of free-flow electrophoresis in a static column by using the low-g environment to suppress the convective mixing associated with joule heating.	Free column electrophoresis was demonstrated despite a failure in the experimental apparatus.	B.1
108	Immiscible Alloy Compositions	Mr. J.L.Reger TWR Systems Group Redondo Beach, CA 90278	Skylab		To thermally process ampoules containing materials exhibiting either liquid or solid state immiscibility in order to determine the properties of the composite material.	Samples of an Au-Ge alloy processed in space exhibited superconductivity of 1.5K while ground-manufactured control samples did not.	B.3
110	Preparation of Silicon Carbide Whisker Reinforced Silver Composite Material in a Weightless Environment	Tomoyaske Kawada National Research Institute for Metals 2-3-12, Nakameguro Meguro-ku, Tokyo Japan	Skylab		To obtain Ag and SIC whisker composites with high density and uniform distribution of whiskers by heating and pressurizing sintered products above the melting point of Ag in a weightless environment.	The whiskers were fairly uniformly distributed in flight samples, whereas they tended to cluster near the top of the ground-manufactured samples. Microhardness was found uniform throughout the flight samples; but only so near the top of ground samples where whiskers tended to congregate. Bend load tests also showed that low-g samples evinced large amounts of ductility, whereas ground samples exhibited brittle fracture.	B.1
112	Seeded, Containerless Solidification of Indium Antimonide	Dr. J.U. Walter University of Alabama in Huntsville Sponsor: NASA	Skylab		To investigate the feasibility of containerless processing of single crystals in space; and demonstrate potential of space for producing them.	Highly perfect single crystals can be prepared by seeded, and by containerless solidification; large crystal could be prepared by this technique as well. Production of homogeneously doped single crystals by containerless techniques appears to be feasible.	B.2
117	Steady State and Segregation Under Zero Gravity InSb	Prof. A.F. Witt MIT Cambridge, Mass. 02139	Skylab		To confirm advantages of zero gravity environment; to obtain basic data on solidifcation to explore the feasibility of electronic materials processing in space.	Dopant distribution was found to be extremely homogeneous.	B.2

TABLE 8-4

INFERRED COMMERCIALIZATION POTENTIAL OF SELECTED SAMPLE INVESTIGATIONS

Code	Title	Inferred Potential
76	Zero-G Processing of Magnets	The advantage of manufacturing very strong magnets in space
80	Electrophoresis Technology	The commercial means for processing pharmaceuticals in space
108	Immiscible Alloy Compositions	Manufacturing materials in space which cannot be made on earth
110	Preparation of a Silicon Carbide	Manufacturing products composed of ultra strong composite materials
112	Seeded Containerless Processing	Manufacturing large single crystals with special optical properties, such as IR detectors
117	Steady State and Segregation	The capacity to manufacture superior semiconductors in the space environment

Table 8-5
Statistical Breakdown of MPS Experiments

Experiment Catagories*		1	2	3	4*	Yield Totals	Percent
Yield Areas** (Breakdown)	1	0	0	0	—	0	0.0
	2	17	14	0	—	31	26.3
	3	1	0	6	—	7	5.9
	4	8	8	7	—	23	19.5
	5	0	2	0	—	2	1.7
	6	1	0	0	—	1	0.8
	7	7	12	35	—	54	45.8
Catagory Totals		34	36	48	N.A.		
Percent		29	30	41	N.A.		

★ Experiment Categories:

1. Demonstration of Processes in Space.
2. Data points collected in a low-gravity facility.
3. Theoretical analysis of research performed by the Bureau of Standards.
4. Development of Equipment/Techniques.

★★ Yield results indicate:

1. Major technical and promising economic advantage.
2. Experimentally proven advantage.
3. Theoretical advantage.
4. Inconclusive despite correct experiment procedure.
5. Inconclusive due to faulty equipment procedure.
6. Definitively negative.
7. Not available or propriatory.

* There are 13 experiments in Catagory 4 which refer to development of equipment or experimental techniques, therefore "Yield Catagories" do not apply.

IX. AREAS OF PROMISE

9.0 Purpose

The object of the previous section was to depict the current status of the MPS program. Although the majority of the investigations performed thus far do not state explicit accomplishments, it is possible to extrapolate reasonably creditable expectations of results from their findings. Examples are provided in the previous section; see Table 8-3.

The purpose of this section is to provide examples of products and processes which, from an initial assessment, represent the highest promise for the commercial application of MPS.

Processes and products of highest promise shown here are of two types:

- Applications extrapolated from results achieved in past experimentation;

- Applications which belong in new areas, not heretofore addressed, whose theoretical foundations portend significant advances in materials properties.

9.1 Criteria for Selection of Candidate Products/Processes

The reason for the commercial processing of materials in space is ultimately economic. Consequently, the field of commercially-oriented MPS applications falls into three broad categories:

(1) manufacturing products in space under favorable economic conditions (see further discussion of pharmaceuticals);

(2) processing materials in space which can be projected to have unique commercial value on Earth (see further discussion of immiscibles);

(3) conducting research and development on materials and/or processes in space which contribute to the improvement of commercial processing on Earth.

Economic considerations impose the following criteria for screening products or processes as potential candidates for MPS.

- High value to weight ratio

  Processing in space is expensive. Current estimates of the gross processing cost, including tare, range from $500,000 to $1,400,000 per kilogram.

For example, the round-trip cost of Shuttle transportation is approximately $2,000 per kilogram. The gross cost of processing includes the carriage of the tares, i.e., the cost of transporting processing equipment and materials storage facilities. It also includes the O&M costs for the materials processing facilities, and a proportionate share of the Shuttle's O&M costs.

Whereas the exact processing cost will depend upon the specific product and process employed, Figure 9-1 exemplifies the estimated gross production costs for a typical product.*

It is obvious that candidate materials for commercial manufacturing in space should be sufficiently light to minimize transportation charges, while valuable enough to insure that the market price offsets the costs attributable to transportation. An example of such products is pharmaceuticals, whose prices range up to billions of dollars per kilogram.

- Potential for process improvement

  The value of a product should increase as its processing improves, and decrease in cost as its processing becomes more efficient. It has been suggested that a greater than 400 to 1 improvement in the effectiveness

* "Commercial Materials Processing in Low-g (MPLG): Overview of Commercialization Activities", a briefing by Marshall Space Flight Center, presented at NASA Headquarters on March 7, 1983.

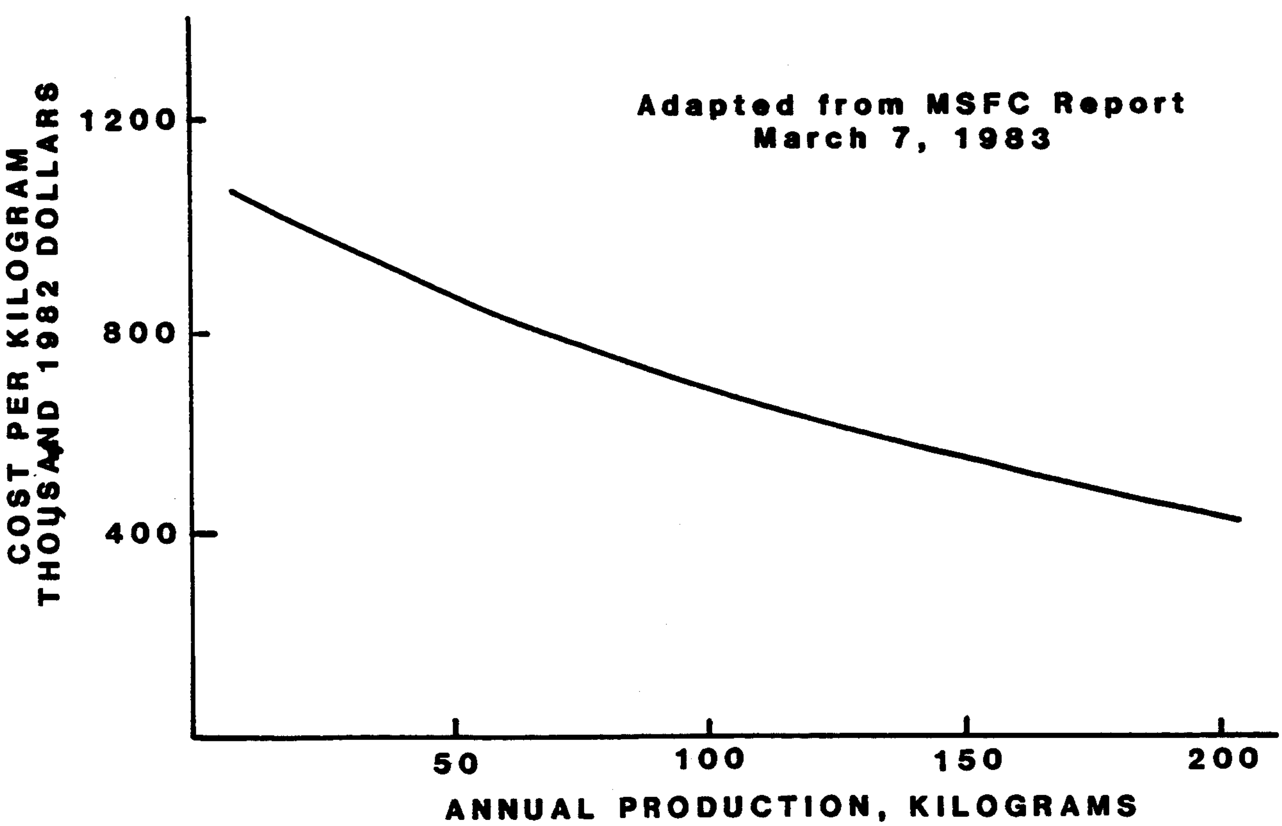


Figure 9-1. Typical Space - Based Production Costs (Monodispersed Latex Spheres)

of space over terrestial processing is a realistic threshold for selecting candidate processes for MPS.*

- Production of unique products

  If a product cannot be adequately processed on Earth but is amenable to space processing, it warrants consideration as a candidate for MPS.

Due to the unique genesis of such a product, Earth-manufactured products may not be competitive with it. The economic criterion would be the revenue which the product could command.

A possible example would be large bodies of metallic glasses. Current Earth-based technology is adequate for manufacturing small beads of metallic glasses only. However, the market for such products has not as yet been established.

9.2 Examples of Products with Commercial Promise

The methodology based upon state-of-progress, indicated in the previous section, can be coupled to the criteria for selection developed above — i.e., high value to weight ratio, potential for process improvement, production of unique products — to extrapolate commercial applications from selected MPS investigations.

In this section, five examples of products with commercial promise are developed. Four pertain to extrapolation of past investigations; one, dealing with strength of materials, is derived from theoretical considerations.

The value of such extrapolations, performed with the proper balance between fantasy and scientific grounding, is that they provide an imaginative yet pragmatic outlook as to what is possible. Experience shows that this approach is most valuable in stimulating the thinking of industrial R&D managers.

The development of the five examples selected follows.

* ibid. MSFC briefing.

9.2.1 Pharmaceuticals

"Pharmaceuticals" or "drugs" are defined, in their broadest sense, as substances that are used in (1) the diagnosis, treatment, mitigation or prevention of disease, abnormal physical states or symptoms thereof, and (2) the restoration, correction and modification of organic functions.

Major drug groups include:

- Anesthetics - causing a loss of sense perception;
- Antiseptics and Germicides - safeguarding against infection;
- Chemotherapeutic drugs - chemicals used to treat or investigate a variety of diseases such as malaria, and abnormal physical states such as cancer;
- Hormones - glandular excretions affecting growth and other bodily functions
- Tranquilizers - inducing a calm mental state;
- Vitamins - complex organic substances essential in small amounts to sustain a variety of body functions essential or important to health.

Drugs are classified in the trade in one of three ways:

- by pharmacological uses, i.e., based upon which bodily functions they affect;
- by therapeutic uses, i.e., according to what conditions they can impact or treat;
- by chemical group.

Pharmacological and therapeutic classifications do not necessarily relate unequivocally to the physical process whereby a drug is produced. Chemical classifications are better suited to this end. Thus the following classification is by chemical group.

Pharmaceuticals comprise a large and diverse universe of ethical drugs, biochemicals and immunochemicals.

- The term ethical drug refers to all drugs of whatever origin whose use conforms to the standards of medical practice. Examples of drugs not considered "ethical" in this country are heroin, LSD and other drugs for which there is no recognized therapeutic use in medicine.

- One subset of ethical drugs is biochemicals, which are drugs of plants and animal origen (as opposed to mineral), whether derived from natural products or by means of laboratory synthesis. Biochemicals range in complexity from simple organic buffers to complex products of metabolism such as vitamin B_{12}.

- Immunochemicals are a subset of biochemicals. They include antisera and antigens, which are used to provide immunity to diseases or to control the advance of maladies or of abnormal bodily functions.

A breakdown of the latter two types into major categories is shown in Figure 9-1. Each of the categories on the bottom tier of the chart represents from tens to hundreds of individual chemical compounds.

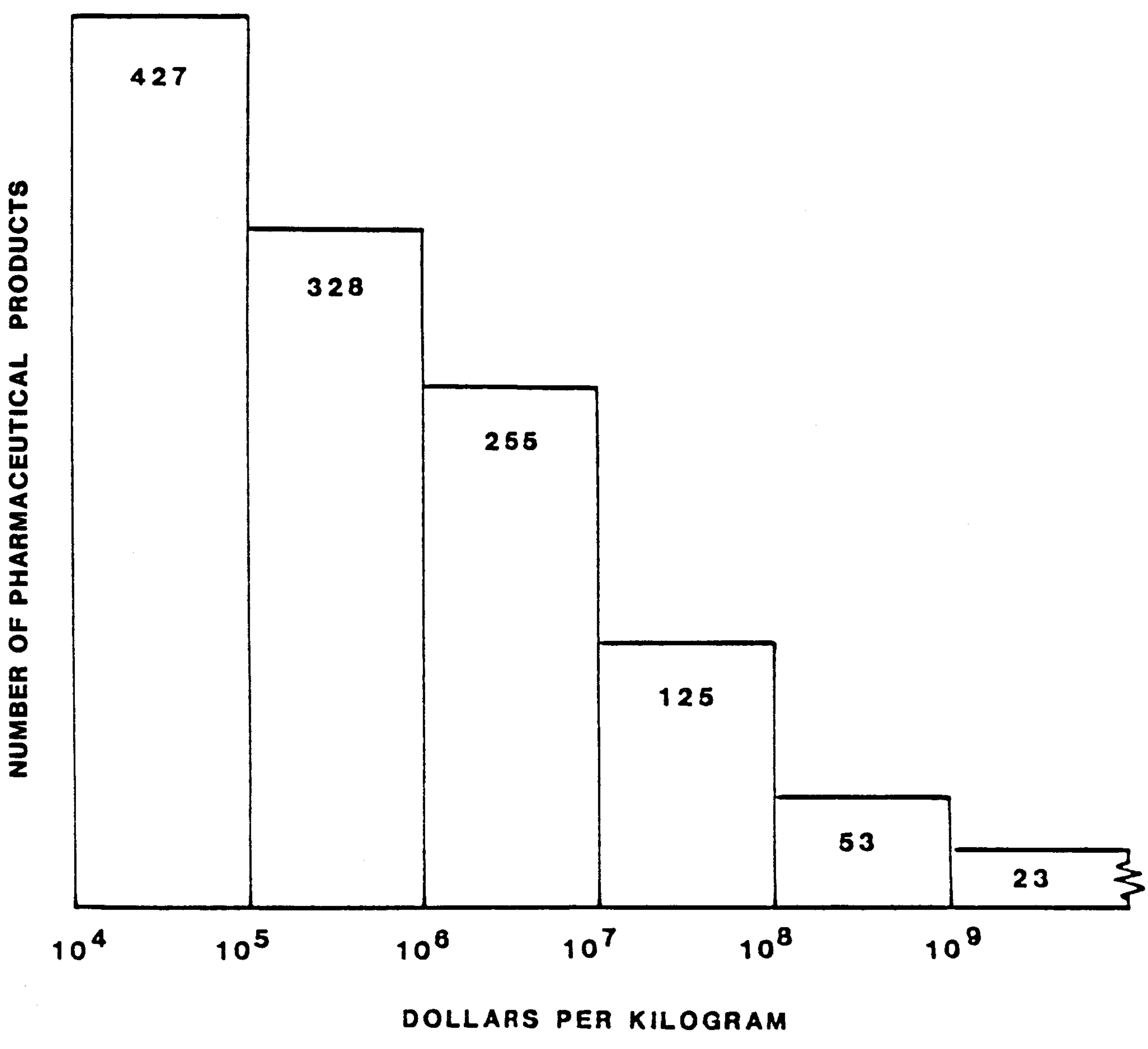
Drugs constitute the most conspicuous category of materials exhibiting the property of high value to weight ratio. Table 9-1 illustrates a sample of drugs that retail for more than $1,000,000,000 per kilogram. Figure 9-2, constructed from a drug specialty catalog, depicts the distribution of numbers of drug types as a function of price. Figure 9-3 shows a product profile of pharmaceuticals.

There is a continuing need in the biomedical community for improved separation and purification techniques for specific products related to cell components, cell by-products and proteins.

TABLE 9-1

SELECTED PHARMACEUTICALS SOLD FOR MORE THAN ONE BILLION DOLLARS PER KILOGRAM

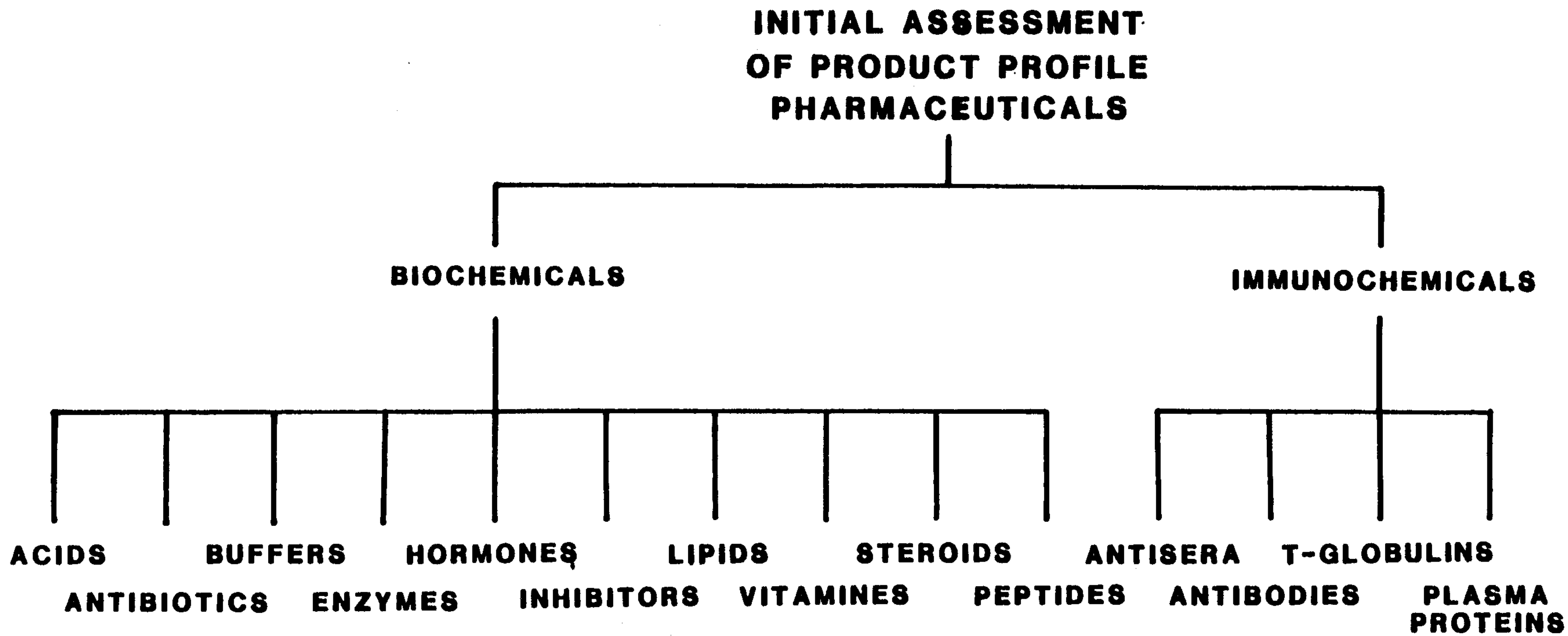
Pharmaceutical	Billion Dollars Per Kilogram
Alfatoxin M_1, Aspergillus flavus	\$ 5.00
Bothropsinase Reagent	14.50
Cholecystokinin Octapeptide	1.80
Chorionic Gonadotropin, (hCG), Human, Iodination grade	3.20
Chymotrypsin, Human Pancreatic, Iodination grade	3.00
C-Peptide, Human, standard	1.80
C-Peptide, Human, Tyrosylated, Iodination grade	8.00
Deoxyribonucleic Acid, SV40	6.25
Ferritin, Human, Spleen, Iodination and standard grade	2.45
α- Feto Protein (AFP), Human, Iodination grade	2.50
α- Feto Protein (AFP), Human	20.00
α- Feto Protein (AFP), Mouse	1.50
Follicle-Stimulating Hormone, (hFSH), Human, Iodination grade	5.60
Growth Hormone, Human (hGH), Iodination grade	2.00
Luteinizing Hormone, Human (hLH), Iodination grade	2.15
Parathyroid Hormone, (PTH), Bovine 1-84, Iodination grade	5.00
Prolactin, Human (hPRL), Iodination grade	2.45
Thyroid-Stimulating Hormone, Human, Pituitary (hTSH), Iodination grade	4.00
Thyroid-Stimulating Hormone, Human, α- subunit, (hTSH), Iodination grade	5.30
Thyroid Stimulating Hormone, Human, β- subunit, (hTSH), Iodination grade	4.36
Trypsin, Human, Pancreas, Iodination grade	3.00
Vinculin, Chicken Gizzard	1.00



*1983 BIOCHEMICAL AND IMMUNOCHEMICAL CATALOG/HOECHST

Representative Costs of Selected Pharmaceuticals.*

Figure 9-2



Product Profiles of Pharmaceuticals

Figure 9-3

Distinct separation is required because these materials are found in very low concentrations, embedded in matrices of other very similar materials, e.g., beta cells in a mixture of cells comprising a pancreas. The process of achieving these materials in concentrated form is thus quite costly.

Purification is important in many cases where the desired, or target drug, can be found in its original form intermixed with substances which are either potentially harmful, or which produce undesired side-effects. High priority candidates for separation and purification in the space environment are beta cells, interferon, epidermal growth factor products, growth hormone products, antitrypsin products and antihemophilic products.

Electrophoresis in microgravity has demonstrated the distinct promise of improved separation and purification. Improved separation is tantamount to higher throughput. Better purification leads to higher-resolution separation between the target material and its background. McDonald Douglas estimates that electrophoretic processing in space can enhance throughput by a factor of perhaps 500, with up to a five-fold increase in purity over Earth-bound processes.

9.2.2 Large Monodispersed Latex Spheres

It was found quite by accident several years ago that a polyvinyl latex, grown by polymerization of a monomer in the presence of a surfactant and water, yielded a vast number of microscopic spherical particles that were nearly identical in size. The size distribution was so narrow that the particles became widely used as calibration standards for electron microscopy. In a short time, a remarkable number of uses was found for these monodispersed particles, ranging from seriological tests for a number of diseases to measuring pore sizes in biological and other membranes.

During the conventional terrestrial growth process, the latex spheres are maintained in suspension by intrinsic Brownian motion until their diameter reaches approximately two microns, at which point they tend to sediment under normal one-g gravity. For larger diameters, the sphere's suspension can be further maintained by gentle stirring; however, extreme care must be taken to prevent flocculation or the initiation of a new batch of particles. For this reason, monodispersed spheres are not commercially available in large sizes. MPS literature identifies the breakover point as occurring at 2 microns, but MSFC researchers communicate that the Dow Chemical Company has recently placed spheres as large as 10-15 microns on the market.

MSFC has developed a unique process which has demonstrated the production of spheres up to 40 microns in diameter, with characteristics of uniformity of diameters and deviation from roundness considerably superior to those achieved commercially. This MSFC process has been tested on the ground. MSFC researchers estimate that significantly improved characteristics of uniformity of diameters, roundness, and diameter upper dimensions, are achievable by microgravity processing.

Ground-produced spheres up to 15 microns in diameter are sold currently in one ounce bottles containing 0.1% solid spheres for $65. This equates to $473,000 per kilogram at retail price. It is believed that larger sizes, up to 40 microns, will command a higher price. MSFC estimates that space production costs for latex spheres will range from $900 per gram for 50 kilograms produced to $500 per gram for 200 kilograms produced annually.*

9.2.3 "Ultra-Soft" Magnetic Materials

The operation of transformers, motors, generators, magnetic memories and other devices which operate with alternating or variable currents and which utilize materials conventionally designated "ferromagnetic" is less than completely efficient in terms of energy transformed versus energy lost. The two primary sources of energy losses are those associated with hysteresis and eddy currents. Losses are caused by heat generated by these effects in the presence of alternating or variable currents.

Eddy current losses are proportional to the square of the frequency of the alternating current. They can be controlled to some extent by the geometry of the ferromagnetic elements employed in these devices. Hysteresis losses are a function of the frequency and are dominated by the choice of ferromagnetic materials.

Hysteresis is the phenomenon whereby the magnetization of ferromagnetic materials (expressed as the flux density, B) "lags" behind the action of the field

* Op cit briefing to NASA Headquarters

(expressed as the magnetic field strength, H). When, in the process of reversing the magnetic field, the magnetic field strength is decreased to zero, the flux density retains some residual value -- termed remanence, residual induction or retentivity.* Conversely, a certain amount of opposite-polarity magnetic field strength is required to cancel out the retentivity. This is known as the coercive force. The integral under the retentivity -- coercive force loop is proportional to the hysteresis loss. Hence, the "softer" the magnetic properties of a ferromagnetic material, the smaller the hysteresis loss and correspondingly the greater the energy efficiency of the device.

An important category of MPS experimentation addressed the production of bulk metallic glasses. The object of this experimentation was to explore the feasibility of containerless processes producing metallic glasses by severe undercooling while eliminating container-induced nucleation sites. The production of small amounts of metallic glass in ground-based research has resulted in the unexpected observation that the Pd-Si-Cu compound selected for experimentation exhibited "very soft" magnetic properties. Thus far, (SPAR) flight experiments have failed due to equipment failure, but work continues to refine the experiments protocol.

Currently, metallic glasses may be made on Earth in very small quantities due to limitations in the technology for rapidly cooling such glasses to the amorphous state, bypassing crystallization. MPS technology portends the possibility of learning to produce macroscale amounts from which to fabricate high-grade, high-frequency laminations or ferrite-like transformer cores.

9.2.4 Immiscible Materials

Immiscible materials represent a broad category of multiphase material systems which exhibit a "miscibility gap" in their phase diagram. That is to say, at a particular relative concentration, one component of the system tends to separate from the other and the two materials cannot be mixed. One classic example is oil and water. Certain metal alloys cannot be made readily because the metals separate when melted and continue to remain distinct upon cooling. Several materials of interest for space processing involve fluid phases, where the effect of gravity on processing could be pronounced.

* Permanent (so called "hand") magnets characteristically have high remanence while "soft magnets" are ferromagnetic materials with low remanences.

From theoretical investigations*, a number of compounds have been identified which might exhibit properties of:

- superconductors,
- electrical contact materials,
- III - V semiconductors,
- catalysts,
- permanent magnets,
- bearings, and
- superplastic materials,

and whose components are immiscible in a fluid phase. For example, nearly 250 materials have been identified as potential superconductors (see Table 9-2).

Skylab experimentation investigated the possibility of preparing immiscible alloys by isothermal and directional solidification. One alloy, 76.85 weight percent gold and 23.15 percent germanium, was selected to be tested because it exhibits almost complete solid state immiscibility. As expected, samples solidified in space were significantly more homogeneous in structure than their counterparts produced on Earth. The space-produced samples exhibited superconductivity at 1.5° K, which ground-manufactured samples did not.

This suggests the value of processing a large number of materials, such as shown in Table 9-2 for further research on Earth, whether the final result is either a better understanding of Earth-bound technology or identification of products of sufficiently unique and valuable characteristics to warrant manufacturing in space.

9.2.5 High-Strength Materials

The object of this subsection is to exemplify the ultimate potential obtainable in the technology of materials processing. The specific example selected pertains to the stress-strain characteristics of materials.

* See Gelles, S.H. Et. Al. 1977. Referenced in Bibliography.

TABLE 9-2

SYSTEMS OF LIQUID PHASE IMMISCIBLE MATERIALS
SUGGESTED FOR SUPERCONDUCTING PROPERTIES

Ag-Cb	B-Bi	Bi-Ru	Cb-Pb	Cr-Sn	Ga-Hg	La-Ta	Mo-Sb	Pu-Ta
Ag-Ir	B-Cd	Bi-Si	Cb-Pu	Cs-Ga	Ga-K	La-Ti	Mo-Sc	Re-Sn
Ag-Mo	B-Ga	Bi-U	Cb-Sc	Cs-In	Ga-Pb	La-U	Mo-Sn	Re-Zn
Ag-Re	B-Hg	Bi-V	Cb-Sn	Cu-Mo	Ga-Te	La-V	Mo-Y	Ru-Zn
Ag-Ru	B-In	Bi-W	Cb-Y	Cu-Os	Ga-Tl	La-Yb	Na-Ta	S-Sn
Ag-Ta	B-Pb	Bi-Zn	Cb-Yb	Cu-Pb	Ga-W	La-Zr	Na-U	S-Tl
Ag-U	B-Sn	C-Cd	Cd-Cr	Cu-Re	Gd-Mo	Li-Mo	Na-Zn	Sc-U
Ag-V	B-Tl	C-Hg	Cd-Fe	Cu-Ru	Gd-Ta	Li-Ta	Na-Zr	Sc-V
Al-As	Be-Bi	C-Pb	Cd-Ga	Cu-Ta	Gd-U	Li-Ti	Nd-Ta	Se-Sn
Al-Bi	Be-Ga	C-Sn	Cd-K	Cu-Tl	Gd-V	Li-U	Nd-Ti	Se-Tl
Al-C	Be-Ge	C-Tl	Cd-Pu	Cu-U	Gd-W	Li-V	Nd-U	Se-Zn
Al-Cd	Be-Hg	C-Zn	Cd-Se	Cu-V	Ge-Hg	Li-Zr	Nd-V	Si-Tl
Al-Cs	Be-In	Ca-Cb	Cd-Si	Dy-Mo	Hg-Sc	Lu-Ta	Ni-Pb	Sm-U
Al-In	Be-Mg	Ca-Cd	Cd-Tc	Dy-Ta	Hg-Si	Lu-U	Os-Sn	Sm-V
Al-K	Be-Pu	Ca-Gd	Ce-Mo	Dy-Ti	Hg-Ta	Lu-V	P-Sn	Sm-W
Al-Na	Be-Sn	Ca-La	Ce-Ta	Dy-U	Hg-V	Mg-Mo	P-Tl	Ta-Tb
Al-Pb	Be-U	Ca-U	Ce-Ti	Dy-V	Hg-W	Mg-Ti	Pb-Pm	Ta-Y
Al-Rb	Bi-C	Cb-Ce	Ce-U	Er-Mo	Ho-U	Mg-U	Pb-Se	Tb-U
Al-S	Bi-Cb	Cb-Cu	Ce-V	Er-Ta	In-S	Mg-V	Pb-Si	Te-Tl
Al-Tl	Bi-Co	Cb-Er	Ce-Zr	Er-Ti	In-Se	Mg-Zr	Pb-U	Th-U
As-Hg	Bi-Cr	Cb-Gd	Co-Hg	Er-U	In-Te	Mn-Pb	Pb-W	Th-Yb
As-Tl	Bi-Pe	Cb-K	Co-Pb	Er-V	K-Mo	Mn-Tl	Pb-Zn	Tl-Zn
Au-Ir	Bi-Ga	Cb-La	Co-Tl	Eu-U	K-Zn	Mo-Nd	Po-Ta	Tm-U
Au-Os	Bi-Ge	Cb-Li	Cr-Gd	Fe-Hg	La-Mn	Mo-Pb	Pr-Ta	U-Y
Au-Re	Bi-Mn	Cb-Mg	Cr-Hg	Fe-Pb	La-Mo	Mo-Po	Pr-Ti	U-Yb
Au-Rh	Bi-Mo	Cb-Na	Cr-Ta	Fe-Sn	La-Pu	Mo-Pr	Pr-U	U-Zn
Au-Ru	Bi-Os	Cb-Nd	Cr-Pb	Fe-Tl	La-Re	Mo-Pu	Pr-V	V-Y
								V-Yb
								W-Zn

A limited number of MPS investigations has shown instances where microgravity processing has yielded tensile strengths up to 50% greater than obtained from the same materials processed under terrestrial gravity. Investigations leading to these results were obstructed by sundry inadequacies and malfunctionings of the experimental equipment which may have inhibited the production of even higher-strength materials. Nevertheless, the promise of achieving materials with above-normal stress-strain characteristics has definitely emerged.

Table 9-3 shows the tensile strengths of materials commonly used in industry for purposes of civil building, machine construction, and applications requiring high structural performance.

Note that the class of materials, represented in Table 9-3 by boron, and generally included within the broad designation of "ceramics", exhibits tensile strengths which are approximately four to five times that of high-strength steel.

The problem with these materials is that they are brittle as well as strong. Brittleness connotes the property of propensity to cracking. Microfractures in ceramics, once started, tend to propagate and enlarge, until the high strength which is characteristic of the pristine material dwindles and crumbles.

This is why, aside from cost considerations, we do not use structural beams fashioned from boron. While initially, immensely strong, a few hammer blows would be sufficient to induce cracking, and soon thereafter the fracturing of the beam.

Modern materials technology has succeeded in exploiting the tensile strength characteristics of ceramic materials by the technique commonly labeled "embedded fiber technology". Small-diameter fibers of boron, for example, are embedded in a matrix of a softer material—e.g., aluminum, and copper. The boron fibers provide the tensile strength and the metal matrix insures protection from cracking.

An even more exciting vista of ultra-strong materials is afforded by the theoretical consideration of the binding forces which underlie the cohesion of matter.

As is well known, the principal intermolecular forces in such a structure are of two kinds: the binding-force attraction between charges of opposite electrical polarity, and

TABLE 9-3

TENSILE STRENGTH OF SELECTED MATERIALS

MATERIAL	TENSILE STRENGTH KG/CM^2
IRON FOR CONCRETE REINFORCEMENT	4,000
STRUCTURAL STEEL	10,000
HIGH-STRENGTH STEEL	22,000
DURALUMINUM	4,500
BORON	99,000

the strong quantum repulsion caused by the physical proximity between material particles. The existence of simple material structures is commonly regarded as resulting from the equilibrium of these two opposing forces.

Table 9-4 illustrates the ideal case of a material structure of the ionic type (ionic crystal), subject to the coulomb attraction between mono-ionic molecules neglecting the repulsive force caused by the strong quantum interaction (which varies with an exponential law of their distance).

The "Mabelungen Factor", indicated in Table 9-4, expresses the integration of the attractive forces between ions of opposite signs with the repulsive forces between homeopolar ionic charges. Note that the ultimate theoretical strength of an ionic material appears to be of order twenty times that of conventionally produced materials.

9.3 Conclusion

In each of the five examples just discussed, products of known or potential value were identified:

Pharmaceuticals: Beta Cells, Interferon, Epidermal Growth Factor, etc.

Large Monodispersed Latex Spheres: The spheres themselves

High Strength Materials: Composites such as SiC/Ag

Ultra-Soft Magnetic Materials: Ferromagnetic parts for high frequency electronic devices

Immiscible Materials: Superconductors

TABLE 9-4

SUPER-STRENGTH MATERIALS II

INTERMOLECULAR IONIC
BINDING FORCE-IDEAL CASE

$$T = \frac{Q^2 \times 10^{-4}}{4 \pi \epsilon R^4 M}$$

T = IDEAL TENSILE STRENGTH, Kg/CM^2

Q = ELECTRON CHARGE = 1.6×10^{-19} COULOMB

$\mathcal{E}$ = DIELECTRIC CONSTANT = 8.84×10^{-12} FARAD/METER

R = INTERMOLECULAR DISTANCE, METERS

M = MABELUNGEN FACTOR

SOLVE FOR BORON CRYSTAL

T = 2,000,000 KG/CM^2

X. INDUSTRY SURVEY FINDINGS

10.0 Direct Query Program

The goal of the direct query program was to appraise the level of the non-aerospace industry's knowledge of and interest in MPS, and to identify industrial requirements for participation in the program.

In support of this goal, the principal objectives of the direct query program were to:

- Assess the best potential candidates for MPS among the products produced and processes employed by selected industries;
- Determine the readiness and willingness of industries to enter into some form of participation in the MPS program;
- Assess the key industrial drivers which motivate or deter participation with NASA in MPS activities;
- Assist in the structuring of a program for NASA-industry cooperation in MPS, corresponding to industrial requirements.

The direct query program was conducted through interviews with key personnel of selected industries. Those persons interviewed were advised that their responses would be kept confidential, i.e., not given general dissemination. The raw data derived from these interviews were distributed to selected NASA officials after permission was granted by the selected industries.

The industries and the personnel who were interviewed are coded alphabetically in the presentation of the survey results which follows.

10.1 Criteria for Selecting Industries to be Queried

Two limiting approaches were available for selecting respondent industries:

- The follow-up approach, i.e., contacting industries known to have already been exposed to MPS concepts, techniques and technologies;

- The sample approach, i.e., contacting industries substantially on a stratified random basis.

Since the intent of this effort was to obtain the widest possible sample of attitudes from U.S. industry, and NASA was already engaged in follow-up activities with several industries, the follow-up approach was rejected in favor of the sampling method.

To focus on plausible candidates, initial sampling criteria were established as follows:

- Non-overlap criterion. MPS customers who are currently negotiating with NASA were not sampled. Thus, aerospace industries were excluded from the sample, as well as the Space Station definition endeavor, and a significant portion of very large companies.

- The stratification criterion. Potential respondents were limited to representatives from those industries which are currently engaged in activities most germane to MPS.

To further delimit the stratification criterion, the following sub-criteria for determining eligible industries were established:

- Industries whose products sell for a significant price per unit weight;

- Industries which engage in high technology processes;

- Industries whose products sell for relatively low prices but in such large quantities and through processes of sufficiently high technology that even minor improvements in processing could result in significant economic advantages;

- Industries whose products and/or processes bear a strong analogy to the products/processes already experimented within NASA's MPS program.

From these sub-criteria, industries such as mining and quarrying (Standard Industrial Classification B-14), and Agricultural/Production (SIC A-01) were eliminated. In fact, a large portion of the SIC categories defined by OMB were eliminated. Such actions, however, should not be considered as final, but only as an initial means to focus quickly upon what appeared to be the most promising industries. It is in fact entirely possible that subsequent in-depth analyses of the "eliminated" industries may reveal unsuspected applications of interest to MPS.

By applying the above criteria and sub-criteria, the following industries were given a most promising status from the outset:

- Medium size industries which specialize in the research, manufacture and development of parmaceuticals, high value chemicals and highly technical and expensive industrial equipment;

- Industries which produce technological materials selling at low cost, but in such large quantities that minor improvements in processing would lead to significant increases in sales and profits. An example of this category is the aluminum industry.

10.2 Information Sought and Gleaned from Direct Queries

Queries to potential customers were based on a hierarchy of meaningful information expectations relating to MPS objectives. A summary of the information sought from possible MPS users is presented in Table 10-1.

Respondents were not expected to address each of the items, per se, that appear in the Table. Rather, information was elicited in an open dialogue, with the interviewer assuming primarily a listening role.

The basic usefulness of the information sought and its relationship to the program's objectives should be apparent from a review of the Table. It may nevertheless be helpful to address its principal features. The information sought falls into 4 categories.

- The first category covers the general business environment and performance of the industry,its R&D endeavors and its principal products. This information

TABLE 10-1

INFORMATION SOUGHT FROM POTENTIAL MPS USERS

1. PROFILE OF COMPANY

   - Annual Sales, Profitability, Areas of Business Endeavor, Areas of Research
   - Normal planning horizon
   - Responsibility of discussant within the company

2. PLANNING FUNCTION.

   - Who in the company, if anyone, is responsible for maintaining awareness of broad business opportunities
   - If no one, how is planning accomplished.
   - If yes, which areas have priority. How are priorities established. How is their "priority rank" measured or assessed.
   - Is space opportunity included. Where does it fit.

3. AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT

   - Has the Company heard of space opportunities. If so, to what extent, how, from whom

   If space opportunities are not included in current planning, is this because:

   - They were never considered
   - They were considered and discarded after limited analysis
   - They were considered and rejected after mature analysis
   - What were the factors that led to the discard decision

4. FUTURE INTEREST

   - Will company seek out space opportunities on their own
   - Should such opportunities be offered to them
   - Who should take the next step: the company or NASA
   - What should be the next step

provides an initial "fix" as to which categories of products, or which type of R&D, emerge as MPS-addressable among the queried industry's activities.

The time span of the particular industry's planning horizon serves to calibrate the "tempo", from initiation to fruition of a new endeavor, within which the respondent industry must normally react.

The discussant's level of responsibility is a measure of how authoritatively he speaks to the company's interest, or is capable of leading or committing the company to MPS-oriented endeavors.

- The second category explores how the respondent industry performs its planning, and, in particular, whether space-oriented opportunities are included in its planning functions.

- The third category is designed to assess whether there is a need on NASA's part for expanded "industry awareness" efforts; and, if such awareness exists, the motivators for acceptance or rejection of space opportunities in the respondent's planning process.

- The fourth category addresses the key questions, "what does it take to interest you in space" and "where do we go from here."

The information elicited from the direct queries is summarized in Tables 10-2 through 10-18. Its significance is discussed following.

TABLE 10-2

SUMMARY OF RESULTS FROM DIRECT QUERIES

INDUSTRY CODE:	A
RESPONDENT CODE:	A-1
1. PROFILE OF COMPANY	
1.1 Annual sales, $Million, 1982	4,300
1.2 Overall Profit margin, pre tax, %	
1.3 Ratio of R&D expenditures to sales %	
1.4 Principal Products addressable by MPS	Pharmaceuticals except blood products
1.5 Sales Volume of the MPS-addressable Products, $ Million	1,100
1.6 Principal Areas of MPS-addressable R&D	Pharmaceuticals
1.7 Planning horizon for Hi-tech products, years	2 to 3
1.8 Responsibility of discussant	Planning of new hi-tech products, direction of R&D
2. PLANNING FUNCTION FOR MPS ADDRESS PRODUCTS AND PROCESSES	
2.1 Who is responsible for planning	Respondent A-1

2.2	If no one, how is planning accomplished	N.A.
2.3	Which areas have priority	Those for which market is most favorable in terms of future profits
2.4	How are priorities established	In terms of profitability
2.5	How are priorities ranked and measured	In terms of profitability
2.6	Is space opportunity included	Not included
2.7	If so, in what area, product, or process	N.A.
3.	AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT (MPS)	
3.1	Has Company heard of MPS opportunities	Yes
3.2	To what extent	General knowledge
3.3	How and from whom	Scientific/Technical literature
3.4	If not, why	N.A.
4.	IF SPACE OPPORTUNITIES ARE NOT INCLUDED IN CURRENT PLANNING	
4.1	To what extent were they considered	To a limited degree
4.2	Were they considered and discarded after limited analysis	Yes

4.3	Were they considered and rejected after mature analysis	No
4.4	What were the factors that led to the discard decision	Limited "thinking" time on the part of senior planners and scientists
5.	**HOW WILL COMPANY SEEK OUT SPACE OPPORTUNITIES**	
5.1	On their own	No
5.2	After opportunities are offered	Yes, if promising
5.3	In what form should opportunities be presented	Not necessary to propose specifics. Stimulating results/examples are sufficient
6.	**THE NEXT STEP**	
6.1	Is the Company interested in further pursuing the exploration of space opportunities	Yes
6.2	If so, who should take the next step: the Company or NASA	NASA
6.3	What should be the next step	Discussion with top-level NASA representatives
6.4	Will the Company consider further steps, or a programmatic approach	Yes. Presentation of opportunities to planners/scientists

TABLE 10-3

SUMMARY OF RESULTS FROM DIRECT QUERIES

INDUSTRY CODE:	B
RESPONDENT CODE:	B-1
1. PROFILE OF COMPANY	
1.1 Annual sales, $ Million, 1982	1,114
1.2 Overall Profit margin, pre-tax, %	13
1.3 Ratio of R&D expenditures to sales %	4.5
1.4 Principal Products addressable by MPS	Medication delivery systems, Laboratory diagnostic equipment
1.5 Sales Volume of the MPS—addressable Products, $ Million	300
1.6 Principal Areas of MPS--addressable R&D	None stated
1.7 Planning horizon, for hi-tech products, Years	None stated
1.8 Responsibility of discussant	Planning improvements and innovations of Company's medical products
2. PLANNING FUNCTION FOR MPS-CANDIDATE PRODUCTS AND PROCESSES	
2.1 Who is responsible for planning	Respondent B-1, together with Marketing Departments

2.2	If no one, how is planning accomplished	N.A.
2.3	Which areas have priority	Those which promise most profitability
2.4	How are priorities established	Based on market forecasts
2.5	How are priorities ranked and measured	Based on market forecasts
2.6	Is space opportunity included	No
2.7	If so, in what area, product, or process	N.A.

3. AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT (MPS)

3.1	Has Company heard of MPS opportunities	Yes
3.2	To what extent	Broad general knowledge
3.3	How and from whom	Scientific/technical literature/contacts with ECOsystems
3.4	If not , why	N.A.

4. IF SPACE OPPORTUNITIES ARE NOT INCLUDED IN CURRENT PLANNING

4.1	To what extent were they considered	To a very limited degree
4.2	Were they considered and discarded after limited analysis	Yes

4.3	Were they considered and rejected after mature analysis	No
4.4	What were the factors that led to the discard decision	Limited "thinking" time on the part of senior planners and scientists
5.	**HOW WILL COMPANY SEEK OUT SPACE OPPORTUNITIES**	
5.1	On their own	No
5.2	After opportunities are offered	Probably, if promising
5.3	In what form should opportunities be presented	Not necessary to propose specifics. Stimulating results examples are sufficient
6.	**THE NEXT STEP**	
6.1	Is the Company interested in further pursuing the exploration of space opportunities	Yes
6.2	If so, who should take the next step: the Company or NASA	NASA
6.3	What should be the next step	Presentation of opportunities to planners/marketeers/scientists
6.4	Will the Company consider further steps, or a programmatic approach	Not defined at this time

TABLE 10-4

SUMMARY OF RESULTS FROM DIRECT QUERIES

INDUSTRY CODE:		C
RESPONDENT CODE:		C-1
1.	PROFILE OF COMPANY	
1.1	Annual sales, $ Million, 1982	6,130
1.2	Overall Profit margin, pre-tax, %	8
1.3	Ratio of R&D expenditures to sales, %	1
1.4	Principal Products addressable By MPS	Chemical Specialties, including catalysts
1.5	Sales Volume of the MPS—addressable Products, $ Million	2,000
1.6	Principal Areas of MPS—addressable R&D	Basic Chemical R&D, Chemical R&D
1.7	Planning horizon, for hi-tech products, years	2-3
1.8	Responsibility of discussant	Planning of New Business Ventures. Planning, directing, implementing R&D.
2.	PLANNING FUNCTION FOR MPS--CANDIDATE PRODUCTS AND PROCESSES	
2.1	Who is responsible for planning	Respondent C-1
2.2	If no one, how is planning accomplished	N.A.

	2.3	Which areas have priority	Those where product profitability promises to be highest
	2.4	How are priorities established	Market forecasts
	2.5	How are priorities ranked and measured	Based on market forecasts
	2.6	Is space opportunity included	No
	2.7	If so, in what area, product, or process	N.A.
3.	AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT (MPS)		
	3.1	Has Company heard of MPS opportunities	Yes
	3.2	To what extent	Broad general information
	3.3	How and from whom	Scientific/Technical literature
	3.4	If not, why	N.A.
4.	IF SPACE OPPORTUNITIES ARE NOT INCLUDED IN CURRENT PLANNING		
	4.1	Were they considered and discarded after limited analysis	Yes
	4.2	Were they considered and rejected after mature analysis	No
	4.3	What were the factors that led to the discard decision	Apriori assumption that MPS is just Public Relations without substance

5.	HOW WILL COMPANY SEEK OUT SPACE OPPORTUNITIES	
5.1	On their own	No
5.2	After opportunities are offered	Yes, if worthwhile
5.3	In what form should opportunities be presented	Specifics if possible. Stimulating analogies from results achieved folling within the Company product line would be considered
6.	THE NEXT STEP	
6.1	Is the Company interested in further pursuing the exploration of space opportunities	Yes
6.2	If so, who should take the next step: the Company or NASA	NASA
6.3	What should be the next step	Discussion with high-level NASA technology representative
6.4	Will the Company consider further steps, or a programmatic approach to space opportunities	Possibly, if intial steps portend availability of worthwhile prospects for products and/or processes.

TABLE 10-5

SUMMARY OF RESULTS FROM DIRECT QUERIES

INDUSTRY CODE:	D
RESPONDENT CODE:	D-1
1. PROFILE OF COMPANY	
1.1 Annual sales, $ Million, 1982	Data withheld
1.2 Overall Profit margin, pre-tax, %	Data withheld
1.3 Ratio of R&D expenditures to sales, %	Data withheld
1.4 Principal Products addressable by MPS	Aluminum sheet products Aluminum forgings and castings
1.5 Sales Volume of the MPS--addressable Products, $ Million	Data withheld
1.6 Principal Areas of MPS--addressable R&D	Large scale aluminum refining, rolling, casting, forging
1.7 Planning horizon, for hi-tech products, years	1-2
1.8 Responsibility of discussant	Director of Research
2. PLANNING FUNCTION FOR MPS--CANDIDATE PRODUCTS AND PROCESSES	
2.1 Who is responsible for planning	Respondent D-1
2.2 If no one, how is planning accomplished	N.A.

2.3	Which areas have priority	Those where product profitability promises to be highest
2.4	How are priorities established	Market forecasts
2.5	How are priorities ranked and measured	Based on market forecasts
2.6	Is space opportunity included	No
2.7	If so, in what area, product, or process	N.A.

3. AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT (MPS)

3.1	Has Company heard of MPS opportunities	Yes
3.2	To what extent	Broad general information
3.3	How and from whom	Scientific/Technical literature and prior calls by NASA or NASA contractor personnel
3.4	If not , why	N.A.

4. IF SPACE OPPORTUNITIES ARE NOT INCLUDED IN CURRENT PLANNING

4.1	Were they considered and discarded after limited analysis	Not considered
4.2	Were they considered and rejected after mature analysis	No
4.3	What were the factors that led to the discard decision	Apriori assumption that MPS cannot contribute to improving low-cost products

5. HOW WILL COMPANY SEEK OUT SPACE OPPORTUNITIES

5.1 On their own	No
5.2 After opportunities are offered	Yes, if worthwhile
5.3 In what form should opportunities be presented	Specifics as much as possible. Show that there is a logical rationale towards generation of commercially viable product.

6. THE NEXT STEP

6.1 Is the Company interested in further pursuing the exploration of space opportunities	Yes
6.2 If so, who should take the next step: the Company or NASA	NASA
6.3 What should be the next step	Focused discussion with high-level NASA technology representative
6.4 Will the Company consider further steps, or a programmatic approach to space opportunities	Possibly, if initial steps portend availability of worthwhile prospects for ultimately producing economically viable product.

TABLE 10-6

SUMMARY OF RESULTS FROM DIRECT QUERIES

INDUSTRY CODE:		E
RESPONDENT CODE:		E-1
1.	PROFILE OF COMPANY	
1.1	Annual sales, $ Million, 1982	Not publicly releasable
1.2	Overall Profit margin, pre-tax, %	Not publicly releasable
1.3	Ratio of R&D expenditures to sales, %	Not publicly releasable
1.4	Principal Products addressable By MPS	High technology, brass and aluminum castings
1.5	Sales Volume of the MPS—addressable Products, $ Million	Not publicly releasable
1.6	Principal Areas of MPS—addressable R&D	High precision machineless spherical castings
1.7	Planning horizon, for hi-tech products, years	1-2
1.8	Responsibility of discussant	Planning of new products, direction of R&D
2.	PLANNING FUNCTION FOR MPS ADDRESS PRODUCTS AND PROCESSES	
2.1	Who is responsible for planning	Respondent E-1
2.2	If no one, how is planning accomplished	N.A.

2.3	Which areas have priority	Those for which market is most favorable in terms of future profits
2.4	How are priorities established	In terms of profitability
2.5	How are priorities ranked and measured	In terms of profitability
2.6	Is space opportunity included	Not included
2.7	If so, in what area, product, or process	N.A.

3. AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT (MPS)

3.1	Has Company heard of MPS opportunities	Yes
3.2	To what extent	Limited knowledge
3.3	How and from whom	Scientific/Technical literature
3.4	If not , why	N.A.

4. IF SPACE OPPORTUNITIES ARE NOT INCLUDED IN CURRENT PLANNING

4.1	To what extent were they considered	Not considered
4.2	Were they considered and discarded after limited analysis	N.A.
4.3	Were they considered and rejected after mature analysis	
4.4	What were the factors that led to the discard decision	N.A.

5. HOW WILL COMPANY SEEK OUT SPACE OPPORTUNITIES

5.1	On their own	No
5.2	After opportunities are offered	Yes, if worthwhile
5.3	In what form should opportunities be presented	Propose specifics

6. THE NEXT STEP

6.1	Is the Company interested in further pursuing the exploration of space opportunities	Yes
6.2	If so, who should take the next step: the Company or NASA	NASA
6.3	What should be the next step	Focused discussion with top-level NASA representatives
6.4	Will the Company consider further steps, or a programmatic approach	Yes, by presenting opportunities to management

TABLE 10-7

SUMMARY OF RESULTS FROM DIRECT QUERIES

INDUSTRY CODE:		F
RESPONDENT CODE:		F-1
1. PROFILE OF COMPANY		
1.1	Annual Sales, $Million, 1982	3,600
1.2	Overall Profit Margin, Pre Tax, %	8.6
1.3	Ratio of R&D Expenditures to Sales %	2.0
1.4	Principal Products Addressable by MPS	Chemicals, Aerospace Materials
1.5	Sales Volume of the MPS-addressable Products, $Million	2,500
1.6	Principal Areas of MPS-addressable R&D	Chemicals, Materials
1.7	Planning Horizon for hi-tech products, years	10
1.8	Responsibility of Discussant	Head of Materials and Civil Science R&D Laboratory
2. PLANNING FUNCTION FOR MPS ADDRESS PRODUCTS AND PROCESSES		
2.1	Who is responsible for planning	Respondent F-1
2.2	If no one, how is planning accomplished	N.A.

2.3	Which areas have priority	None as yet
2.4	How are priorities established	By assessing commercial prospects
2.5	How are priorities ranked and measured	On cost, prospects, and time-scale
2.6	Is space opportunity included	Yes
2.7	If so, in what area, product, or process	Not yet in specific areas

3. AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT (MPS)

3.1	Has Company heard of MPS opportunities	Yes
3.2	To what extent	At conferences
3.3	How and from whom	Attended a conference at NBS organized by NASA
3.4	If not, why	N.A.

4. IF SPACE OPPORTUNITIES ARE NOT INCLUDED IN CURRENT PLANNING

4.1	To what extent were they considered	Not applicable
4.2	Were they considered and discarded after limited analysis	Not applicable
4.3	Were they considered and rejected after mature analysis	Not applicable

4.4	What were the factors that led to the discard decision	Not applicable
5.	**HOW WILL COMPANY SEEK OUT SPACE OPPORTUNITIES**	
5.1	On their own	No
5.2	After opportunities are offered	Yes
5.3	In what form should opportunities be presented	A presentation to senior staff by a NASA representative followed by discussion.
6.	**THE NEXT STEP**	
6.1	Is the Company interested in further pursuing the exploration of space opportunities	Yes
6.2	If so, who should take the next step: the Company or NASA	NASA
6.3	What should be the next step	See 5.3
6.4	Will the Company consider further steps, or a programmatic approach	Yes

TABLE 10-8

SUMMARY OF RESULTS FROM DIRECT QUERIES

INDUSTRY CODE:		G
RESPONDENT CODE:		G-1
1.	PROFILE OF COMPANY	
1.1	Annual Sales, $Million, 1982	4,113
1.2	Overall Profit Margin, Pre Tax, %	5.5
1.3	Ratio of R&D Expenditures to Sales %	5.1
1.4	Principal Products Addressable by MPS	Electronics components
1.5	Sales Volume of the MPS-addressable Products, $Million	1,594
1.6	Principal Areas of MPS-addressable R&D	Solid state science, plastics, composites
1.7	Planning Horizon for Hi-tech Products, Years	12
1.8	Responsibility of Discussant	Research Manager, Advanced Technology Lab -- Materials Processing
2.	PLANNING FUNCTION FOR MPS ADDRESS PRODUCTS AND PROCESSES	
2.1	Who is responsible for planning	No one
2.2	If no one, how is planning accomplished	They hope it will evolve

2.3	Which areas have priority	None as yet
2.4	How are priorities established	Not applicable
2.5	How are priorities ranked and measured	Not applicable
2.6	Is space opportunity included	It is not excluded
2.7	If so, in what area, product, or process	Materials
3.	AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT (MPS)	
3.1	Has Company heard of MPS opportunities	Yes
3.2	To what extent	Not in enough detail
3.3	How and from whom	From media and journals
3.4	If not, why	N.A.
4.	IF SPACE OPPORTUNITIES ARE NOT INCLUDED IN CURRENT PLANNING	
4.1	To what extent were they considered	They need more information
4.2	Were they considered and discarded after limited analysis	No
4.3	Were they considered and rejected after mature analysis	No
4.4	What were the factors that led to the discard decision	Not applicable

5.	**HOW WILL COMPANY SEEK OUT SPACE OPPORTUNITIES**	
5.1	On their own	No
5.2	After opportunities are offered	Yes
5.3	In what form should opportunities be presented	A seminar or presentation to senior staff by someone from NASA
6.	**THE NEXT STEP**	
6.1	Is the Company interested in further pursuing the exploration of space opportunities	Yes
6.2	If so, who should take the next step: the Company or NASA	NASA
6.3	What should be the next step	A seminar at the company
6.4	Will the Company consider further steps, or a programmatic approach	Yes, if relevant opportunities are identified

TABLE 10-9

SUMMARY OF RESULTS FROM DIRECT QUERIES

INDUSTRY CODE:	H
RESPONDENT CODE:	H-1
1. PROFILE OF COMPANY	
1.1 Annual Sales, $Million, 1982	1,093
1.2 Overall Profit Margin, Pre Tax, %	5.7
1.3 Ratio of R&D Expenditures to Sales %	2.3
1.4 Principal Products Addressable by MPS	Telecommunications equipment
1.5 Sales Volume of the MPS-addressable Products, $Million	1,093
1.6 Principal Areas of MPS-addressable R&D	Special materials
1.7 Planning Horizon for Hi-tech Products, Years	15
1.8 Responsibility of Discussant	Responsible for space applications
2. PLANNING FUNCTION FOR MPS ADDRESS PRODUCTS AND PROCESSES	
2.1 Who is responsible for planning	Senior Director
2.2 If no one, how is planning accomplished	N.A.

2.3	Which areas have priority	None as yet
2.4	How are priorities established	Commercially
2.5	How are priorities ranked and measured	On cost-benefit basis
2.6	Is space opportunity included	Yes
2.7	If so, in what area, product, or process	Not specific

3. AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT (MPS)

3.1	Has Company heard of MPS opportunities	Yes
3.2	To what extent	Not in enough detail
3.3	How and from whom	From technical journals
3.4	If not, why	N.A.

4. IF SPACE OPPORTUNITIES ARE NOT INCLUDED IN CURRENT PLANNING

4.1	To what extent were they considered	Not in detail
4.2	Were they considered and discarded after limited analysis	No
4.3	Were they considered and rejected after mature analysis	No
4.4	What were the factors that led to the discard decision	Not stated

5. HOW WILL COMPANY SEEK OUT SPACE OPPORTUNITIES

5.1	On their own	No
5.2	After opportunities are offered	Yes

5.3	In what form should opportunities be presented	A seminar to senior staff at the Fairchild Lab given by Trantek or NASA

6. THE NEXT STEP

6.1	Is the Company interested in further pursuing the exploration of space opportunities	Yes
6.2	If so, who should take the next step: the Company or NASA	NASA
6.3	What should be the next step	See 5.3
6.4	Will the Company consider further steps, or a programmatic approach	Yes

TABLE 10-10

SUMMARY OF RESULTS FROM DIRECT QUERIES

INDUSTRY CODE:		I
RESPONDENT CODE:		I-I
I. PROFILE OF COMPANY		
1.1	Annual Sales, $Million, 1982	34,400
1.2	Overall Profit Margin, Pre Tax, %	23.0
1.3	Ratio of R&D Expenditures to Sales %	6.1
1.4	Principal Products Addressable by MPS	Materials for micro-circuitry
1.5	Sales Volume of the MPS-addressable Products, $Million	150 (estimate)
1.6	Principal Areas of MPS-addressable R&D	Materials, fundamental research
1.7	Planning Horizon for Hi-tech Products, Years	15
1.8	Responsibility of Discussant	Long-term research on materials
2. PLANNING FUNCTION FOR MPS ADDRESS PRODUCTS AND PROCESSES		
2.1	Who is responsible for planning	Respondent I-I
2.2	If no one, how is planning accomplished	N.A.

2.3	Which areas have priority	Polymers, high strength materials, laminators, packaging and assembly
2.4	How are priorities established	By brainstorming and discussions
2.5	How are priorities ranked and measured	Commercially and by time-scale
2.6	Is space opportunity included	Yes
2.7	If so, in what area, product, or process	Special materials for semi-conductor packaging, etc.

3. AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT (MPS)

3.1	Has Company heard of MPS opportunities	Yes
3.2	To what extent	Not in detail
3.3	How and from whom	At a NASA 'Spin-off' Conference
3.4	If not, why	N.A.

4. IF SPACE OPPORTUNITIES ARE NOT INCLUDED IN CURRENT PLANNING

4.1	To what extent were they considered	None stated
4.2	Were they considered and discarded after limited analysis	None stated
4.3	Were they considered and rejected after mature analysis	None stated

4.4	What were the factors that led to the discard decision	None stated

5. HOW WILL COMPANY SEEK OUT SPACE OPPORTUNITIES

5.1	On their own	No
5.2	After opportunities are offered	Yes
5.3	In what form should opportunities be presented	A symposium would be welcome, given by NASA

6. THE NEXT STEP

6.1	Is the Company interested in further pursuing the exploration of space opportunities	Yes
6.2	If so, who should take the next step: the Company or NASA	NASA
6.3	What should be the next step	See 5.3
6.4	Will the Company consider further steps, or a programmatic approach	Yes, in collaboration with NASA

TABLE 10-11

SUMMARY OF RESULTS FROM DIRECT QUERIES

INDUSTRY CODE:	J
RESPONDENT CODE:	J-1
1. PROFILE OF COMPANY	
1.1 Annual Sales, $Million, 1982	26,500
1.2 Overall Profit Margin, Pre Tax, %	10.4
1.3 Ratio of R&D Expenditures to Sales %	6.4
1.4 Principal Products Addressable by MPS	None yet identified
1.5 Sales Volume of the MPS-addressable Products, $Million	Possibly 200
1.6 Principal Areas of MPS-addressable R&D	Materials, electronics
1.7 Planning Horizon for Hi-tech Products, Years	10
1.8 Responsibility of Discussant	Program Manager for Advanced Programs
2. PLANNING FUNCTION FOR MPS ADDRESS PRODUCTS AND PROCESSES	
2.1 Who is responsible for planning	Respondent J-1
2.2 If no one, how is planning accomplished	N.A.
2.3 Which areas have priority	None yet identified

2.4	How are priorities established	Not stated
2.5	How are priorities ranked and measured	Not stated
2.6	Is space opportunity included	Yes
2.7	If so, in what area, product, or process	Materials electronics

3. AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT (MPS)

3.1	Has Company heard of MPS opportunities	Yes
3.2	To what extent	Only a little
3.3	How and from whom	Attended a NASA 'Spin-off' meeting in 1982, but MPS was only touched on
3.4	If not, why	N.A.

4. IF SPACE OPPORTUNITIES ARE NOT INCLUDED IN CURRENT PLANNING

4.1	To what extent were they considered	Limited
4.2	Were they considered and discarded after limited analysis	Not stated
4.3	Were they considered and rejected after mature analysis	Not stated
4.4	What were the factors that led to the discard decision	N.A.

5.	**HOW WILL COMPANY SEEK OUT SPACE OPPORTUNITIES**	
5.1	On their own	No
5.2	After opportunities are offered	Yes
5.3	In what form should opportunities be presented	At a seminar held at GE by Trantek or NASA
6.	**THE NEXT STEP**	
6.1	Is the Company interested in further pursuing the exploration of space opportunities	Yes
6.2	If so, who should take the next step: the Company or NASA	NASA
6.3	What should be the next step	A seminar
6.4	Will the Company consider further steps, or a programmatic approach	Yes

TABLE 10-12

SUMMARY OF RESULTS FROM DIRECT QUERIES

INDUSTRY CODE:	K
RESPONDENT CODE:	K-1
1. PROFILE OF COMPANY	
1.1 Annual Sales, $Million, 1982	280
1.2 Overall Profit Margin, Pre Tax, %	17.9
1.3 Ratio of R&D Expenditures to Sales %	Very little R&D
1.4 Principal Products Addressable by MPS	None as yet
1.5 Sales Volume of the MPS-addressable Products, $Million	Unsure
1.6 Principal Areas of MPS-addressable R&D	None
1.7 Planning Horizon for Hi-tech Products, Years	10
1.8 Responsibility of Discussant	Assistant to President
2. PLANNING FUNCTION FOR MPS ADDRESS PRODUCTS AND PROCESSES	
2.1 Who is responsible for planning	President
2.2 If no one, how is planning accomplished	N.A.
2.3 Which areas have priority	Long distance communications

2.4	How are priorities established	Commercially
2.5	How are priorities ranked and measured	Commercially
2.6	Is space opportunity included	Yes
2.7	If so, in what area, product, or process	In general terms

3. AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT (MPS)

3.1	Has Company heard of MPS opportunities	Yes
3.2	To what extent	Not much
3.3	How and from whom	Media
3.4	If not, why	N.A.

4. IF SPACE OPPORTUNITIES ARE NOT INCLUDED IN CURRENT PLANNING

4.1	To what extent were they considered	Not much
4.2	Were they considered and discarded after limited analysis	Not yet relevant
4.3	Were they considered and rejected after mature analysis	No
4.4	What were the factors that led to the discard decision	N.A.

5.	HOW WILL COMPANY SEEK OUT SPACE OPPORTUNITIES	
5.1	On their own	No
5.2	After opportunities are offered	Yes
5.3	In what form should opportunities be presented	NASA should advise them if relevant information becomes available
6.	THE NEXT STEP	
6.1	Is the Company interested in further pursuing the exploration of space opportunities	Yes, but only peripherally
6.2	If so, who should take the next step: the Company or NASA	NASA
6.3	What should be the next step	Keep them informed on progress
6.4	Will the Company consider further steps, or a programmatic approach	Yes

TABLE 10-13

SUMMARY OF RESULTS FROM DIRECT QUERIES

INDUSTRY CODE:		L
RESPONDENT CODE:		L-1
1. PROFILE OF COMPANY		
1.1	Annual Sales, $Million, 1982	458
1.2	Overall Profit Margin, Pre Tax, %	5.7
1.3	Ratio of R&D Expenditures to Sales %	Probably less than 2%
1.4	Principal Products Addressable by MPS	None as yet
1.5	Sales Volume of the MPS-addressable Products, $Million	Unsure
1.6	Principal Areas of MPS-addressable R&D	None
1.7	Planning Horizon for Hi-tech Products, Years	5
1.8	Responsibility of Discussant	Director of Business Development
2. PLANNING FUNCTION FOR MPS ADDRESS PRODUCTS AND PROCESSES		
2.1	Who is responsible for planning	Respondent L-1
2.2	If no one, how is planning accomplished	N.A.
2.3	Which areas have priority	Energy technology, e.g., 'H' coal

2.4	How are priorities established	Commercially
2.5	How are priorities ranked and measured	Commercially
2.6	Is space opportunity included	Not really, not considered relevant
2.7	If so, in what area, product, or process	N.A.

3. AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT (MPS)

3.1	Has Company heard of MPS opportunities	Not much
3.2	To what extent	Not much
3.3	How and from whom	Media
3.4	If not, why	N.A.

4. IF SPACE OPPORTUNITIES ARE NOT INCLUDED IN CURRENT PLANNING

4.1	To what extent were they considered	Very little
4.2	Were they considered and discarded after limited analysis	No
4.3	Were they considered and rejected after mature analysis	No
4.4	What were the factors that led to the discard decision	Not relevant

5. HOW WILL COMPANY SEEK OUT SPACE OPPORTUNITIES

5.1	On their own	No
5.2	After opportunities are offered	Probably not
5.3	In what form should opportunities be presented	None stated

6. THE NEXT STEP

6.1	Is the Company interested in further pursuing the exploration of space opportunities	Not much
6.2	If so, who should take the next step: the Company or NASA	Not NASA
6.3	What should be the next step	Not stated
6.4	Will the Company consider further steps, or a programmatic approach	Probably not

TABLE 10-14

SUMMARY OF RESULTS FROM DIRECT QUERIES

INDUSTRY CODE:		M
RESPONDENT CODE:		M-1
1. PROFILE OF COMPANY		
1.1	Annual Sales, $Million, 1982	3,062
1.2	Overall Profit Margin, Pre Tax, %	They lost 2.5 % in 1982 In 1981 they made 5.8%
1.3	Ratio of R&D Expenditures to Sales %	3.1
1.4	Principal Products Addressable by MPS	Special materials, laminates polymers
1.5	Sales Volume of the MPS-addressable Products, $Million	542
1.6	Principal Areas of MPS-addressable R&D	Materials research and processing technology
1.7	Planning Horizon for Hi-tech Products, Years	10
1.8	Responsibility of Discussant	Materials research
2. PLANNING FUNCTION FOR MPS ADDRESS PRODUCTS AND PROCESSES		
2.1	Who is responsible for planning	Respondent M-1
2.2	If no one, how is planning accomplished	N.A.

2.3	Which areas have priority	Special materials
2.4	How are priorities established	By peer review
2.5	How are priorities ranked and measured	On cost-benefit grounds
2.6	Is space opportunity included	Yes
2.7	If so, in what area, product, or process	They are keeping all options open

3. AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT (MPS)

3.1	Has Company heard of MPS opportunities	Yes
3.2	To what extent	They are working closely with Grumman
3.3	How and from whom	Via journals and conferences
3.4	If not, why	N.A.

4. IF SPACE OPPORTUNITIES ARE NOT INCLUDED IN CURRENT PLANNING

4.1	To what extent were they considered	limited
4.2	Were they considered and discarded after limited analysis	No
4.3	Were they considered and rejected after mature analysis	No
4.4	What were the factors that led to the discard decision	N.A.

5. HOW WILL COMPANY SEEK OUT SPACE OPPORTUNITIES

5.1	On their own	No
5.2	After opportunities are offered	Yes
5.3	In what form should opportunities be presented	Via Grumman

6. THE NEXT STEP

6.1	Is the Company interested in further pursuing the exploration of space opportunities	Yes
6.2	If so, who should take the next step: the Company or NASA	NASA via Grumman
6.3	What should be the next step	NASA should review Grumman's proposals which incorporate Celanese ideas
6.4	Will the Company consider further steps, or a programmatic approach	Yes with Grumman

TABLE 10-15

SUMMARY OF RESULTS FROM DIRECT QUERIES

INDUSTRY CODE:		N
RESPONDENT CODE:		N-1
1. PROFILE OF COMPANY		
1.1	Annual Sales, $Million, 1982	2,981
1.2	Overall Profit Margin, Pre Tax, %	They lost 2.8% in 1982 but made 7.6% in 1980
1.3	Ratio of R&D Expenditures to Sales %	R&D expenditure is negligible
1.4	Principal Products Addressable by MPS	Possibly some materials
1.5	Sales Volume of the MPS-addressable Products, $Million	Not identified
1.6	Principal Areas of MPS-addressable R&D	None
1.7	Planning Horizon for Hi-tech Products, Years	4 or less
1.8	Responsibility of Discussant	Research on aluminum
2. PLANNING FUNCTION FOR MPS ADDRESS PRODUCTS AND PROCESSES		
2.1	Who is responsible for planning	No-one specifically for MPS
2.2	If no one, how is planning accomplished	It is not
2.3	Which areas have priority	None in MPS

2.4	How are priorities established	Not stated
2.5	How are priorities ranked and measured	Not stated
2.6	Is space opportunity included	Not really
2.7	If so, in what area, product, or process	N.A.

3. AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT (MPS)

3.1	Has Company heard of MPS opportunities	Yes
3.2	To what extent	Not much; Attended a NASA briefing
3.3	How and from whom	NASA Brief
3.4	If not, why	N.A.

4. IF SPACE OPPORTUNITIES ARE NOT INCLUDED IN CURRENT PLANNING

4.1	To what extent were they considered	The company has serious problems due to the slump in use of aluminum and the high cost of electricity. This has dominated planning activity
4.2	Were they considered and discarded after limited analysis	No
4.3	Were they considered and rejected after mature analysis	No

4.4	What were the factors that led to the discard decision	None
5.	**HOW WILL COMPANY SEEK OUT SPACE OPPORTUNITIES**	
5.1	On their own	Probably not at all
5.2	After opportunities are offered	Probably not
5.3	In what form should opportunities be presented	None
6.	**THE NEXT STEP**	
6.1	Is the Company interested in further pursuing the exploration of space opportunities	Not really
6.2	If so, who should take the next step: the Company or NASA	No-one
6.3	What should be the next step	No-one
6.4	Will the Company consider further steps, or a programmatic approach	Not at this time

TABLE 10-16

SUMMARY OF RESULTS FROM DIRECT QUERIES

INDUSTRY CODE:		O
RESPONDENT CODE:		O-1
1. PROFILE OF COMPANY		
1.1	Annual Sales, $Million, 1982	117.8
1.2	Overall Profit Margin, Pre Tax, %	6.0
1.3	Ratio of R&D Expenditures to Sales %	5.0
1.4	Principal Products Addressable by MPS	Advanced materials
1.5	Sales Volume of the MPS-addressable Products, $Million	2 (estimate)
1.6	Principal Areas of MPS-addressable R&D	Negligible
1.7	Planning Horizon for Hi-tech Products, Years	5
1.8	Responsibility of Discussant	General technology
2. PLANNING FUNCTION FOR MPS ADDRESS PRODUCTS AND PROCESSES		
2.1	Who is responsible for planning	No-one
2.2	If no one, how is planning accomplished	It is not
2.3	Which areas have priority	None

2.4	How are priorities established	Not stated
2.5	How are priorities ranked and measured	Not stated
2.6	Is space opportunity included	Not really
2.7	If so, in what area, product, or process	Not stated

3. AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT (MPS)

3.1	Has Company heard of MPS opportunities	Barely
3.2	To what extent	Not stated
3.3	How and from whom	Media
3.4	If not, why	N.A.

4. IF SPACE OPPORTUNITIES ARE NOT INCLUDED IN CURRENT PLANNING

4.1	To what extent were they considered	Not relevant
4.2	Were they considered and discarded after limited analysis	Essentially, yes
4.3	Were they considered and rejected after mature analysis	No
4.4	What were the factors that led to the discard decision	Not very relevant

5. HOW WILL COMPANY SEEK OUT SPACE OPPORTUNITIES

5.1	On their own	No
5.2	After opportunities are offered	Probably not
5.3	In what form should opportunities be presented	None stated

6. THE NEXT STEP

6.1	Is the Company interested in further pursuing the exploration of space opportunities	Not really
6.2	If so, who should take the next step: the Company or NASA	No-one
6.3	What should be the next step	None
6.4	Will the Company consider further steps, or a programmatic approach	Probably not

TABLE 10-17

SUMMARY OF RESULTS FROM DIRECT QUERIES

INDUSTRY CODE:		P
RESPONDENT CODE:		P-1
1. PROFILE OF COMPANY		
1.1	Annual Sales, $Million, 1982	Not published. Probably in range 5 to 10
1.2	Overall Profit Margin, Pre Tax, %	Barely profitable
1.3	Ratio of R&D Expenditures to Sales %	40
1.4	Principal Products Addressable by MPS	None - as yet
1.5	Sales Volume of the MPS-addressable Products, $Million	N.A.
1.6	Principal Areas of MPS-addressable R&D	Biological programmes
1.7	Planning Horizon for Bi-tech Products, Years	10
1.8	Responsibility of Discussant	Director of all Genetic Engineering Research
2. PLANNING FUNCTION FOR MPS ADDRESS PRODUCTS AND PROCESSES		
2.1	Who is responsible for planning	Respondent P-1
2.2	If no one, how is planning accomplished	N.A.
2.3	Which areas have priority	None as yet

2.4	How are priorities established	Not stated
2.5	How are priorities ranked and measured	Not stated
2.6	Is space opportunity included	Yes
2.7	If so, in what area, product, or process	Biological processes
3.	**AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT (MPS)**	
3.1	Has Company heard of MPS opportunities	Yes
3.2	To what extent	Considerable
3.3	How and from whom	Three Genex executives visited Gerald Sofeen four months ago to discuss NASA's biological programmes in space
3.4	If not, why	
4.	**IF SPACE OPPORTUNITIES ARE NOT INCLUDED IN CURRENT PLANNING**	
4.1	To what extent were they considered	They are
4.2	Were they considered and discarded after limited analysis	Not stated
4.3	Were they considered and rejected after mature analysis	Not stated
4.4	What were the factors that led to the discard decision	Not stated

5. HOW WILL COMPANY SEEK OUT SPACE OPPORTUNITIES

5.1	On their own	No
5.2	After opportunities are offered	Yes
5.3	In what form should opportunities be presented	NASA should keep them informed

6. THE NEXT STEP

6.1	Is the Company interested in further pursuing the exploration of space opportunities	Yes
6.2	If so, who should take the next step: the Company or NASA	NASA
6.3	What should be the next step	See 5.3
6.4	Will the Company consider further steps, or a programmatic approach	Yes, if relevant

TABLE 10-18

SUMMARY OF RESULTS FROM DIRECT QUERIES

INDUSTRY CODE:		Q
RESPONDENT CODE:		Q-1
1. PROFILE OF COMPANY		
1.1	Annual Sales, $Million, 1982	7,000
1.2	Overall Profit Margin, Pre Tax, %	15.6%
1.3	Ratio of R&D Expenditures to Sales %	1%
1.4	Principal Products Addressable by MPS	Chemicals, Fiber Products Biotechnology, Catalysts, Tools, Oil Rigs, Sporting Goods, Retail Sales, Food
1.5	Sales Volume of the MPS-addressable Products, $Million	613
1.6	Principal Areas of MPS-addressable R&D	Pharmaceuticals, Chemicals, Biotechnology
1.7	Planning Horizon for Hi-tech Products, Years	1 to 2
1.8	Responsibility of Discussant	Planning of New Hi-tech Products, Direction of R&D
2. PLANNING FUNCTION FOR MPS ADDRESS PRODUCTS AND PROCESSES		
2.1	Who is responsible for planning	Respondent Q-1

2.2	If no one, how is planning accomplished	N.A.
2.3	Which areas have priority	Those for which market is most favorable in terms of future profits — near term.
2.4	How are priorities established	In terms of profitability
2.5	How are priorities ranked and measured	In terms of profitability
2.6	Is space opportunity included	Not included now - but both Crystal Growth & Latex Spheres are attractive
2.7	If so, in what area, product, or process	Pharmaceuticals, Catalysts Electro-Optical Devices, Integrated Circuit Technology

3. AWARENESS OF OPPORTUNITY OFFERED BY SPACE ENVIRONMENT (MPS)

3.1	Has Company heard of MPS opportunities	Yes
3.2	To what extent	General Knowledge
3.3	How and from whom	Scientific/Technical Literature, Now Visit to HSV
3.4	If not, why	N.A.

4. IF SPACE OPPORTUNITIES ARE NOT INCLUDED IN CURRENT PLANNING

4.1	To what extent were they considered	None

4.2	Were they considered and discarded after limited analysis	No - not sufficient awareness of MPS progress
4.3	Were they considered and rejected after mature analysis	No
4.4	What were the factors that led to the discard decision	N.A.
5.	**HOW WILL COMPANY SEEK OUT SPACE OPPORTUNITIES**	
5.1	On their own	No
5.2	After opportunities are offered	Yes, if promising
5.3	In what form should opportunities be presented	Visit to NASA Research was presented
6.	**THE NEXT STEP**	
6.1	Is the Company interested in further pursuing the exploration of space opportunities	Yes
6.2	If so, who should take the next step: the Company or NASA	The Director of Research now wants to pursue a joint venture in MPS
6.3	What should be the next step	Discussion with top-level NASA representatives
6.4	Will the Company consider further steps, or a programmatic approach	Yes. Presentation of opportunities to planners/scientists

10.3 Synopsis of Responses to Industry Surveys

It was felt that a Table providing an "at-a-glance" capsulization of the responses would be a valuable tool for both analysis and ease in grasping the overall response picture.

Reviewing the thirty questions posed to industry R&D managers, it can be seen that twelve are used to amplify responses to key questions. In eliminating the twelve support questions, the remaining eighteen provide excellent insight to each company's general financial picture, and more important, its understanding of and feelings toward MPS. These eighteen key questions and answers selected from the original thirty are used to create Table 10-19. The paragraphs which follow, extrapolate information from this Table providing a more complete analysis and a summary of findings.

10.4 General Profile of Responses

All sixteen companies indicated some awareness of MPS; however, only two of these companies demonstrated more than a rudimentary knowledge of the program. Scientific and technical journals provided approximately 50% of their information; NASA conferences and the media each contributed approximately 25% (See Figure 10-1).

Most companies responded favorably to MPS. They were quite candid and most were open to future discussions and opportunities relating to the program.

Finally, and most important, all sixteen profiled companies expected NASA to initiate future dialogue on MPS. There was a strong desire in this respect for NASA to present specific examples of MPS investigations to each company.

For a synopsis of these industrial responses, see Figure 10-2 "Response Profile".

10.5 Potential MPS Market Compared to Total Company Sales

Fourteen of the sixteen companies provided information on total yearly sales. Ten of these provided additional figures from which it was possible to compute the sales volume of MPS addressable output. These ten companies account for a combined yearly sales volume of approximately $83.5 billion. The total MPS addressable sales volume of these ten is approximately $11.5 billion or 14% of their combined yearly sales. The corresponding statistics are graphically presented in Figure 10-3.

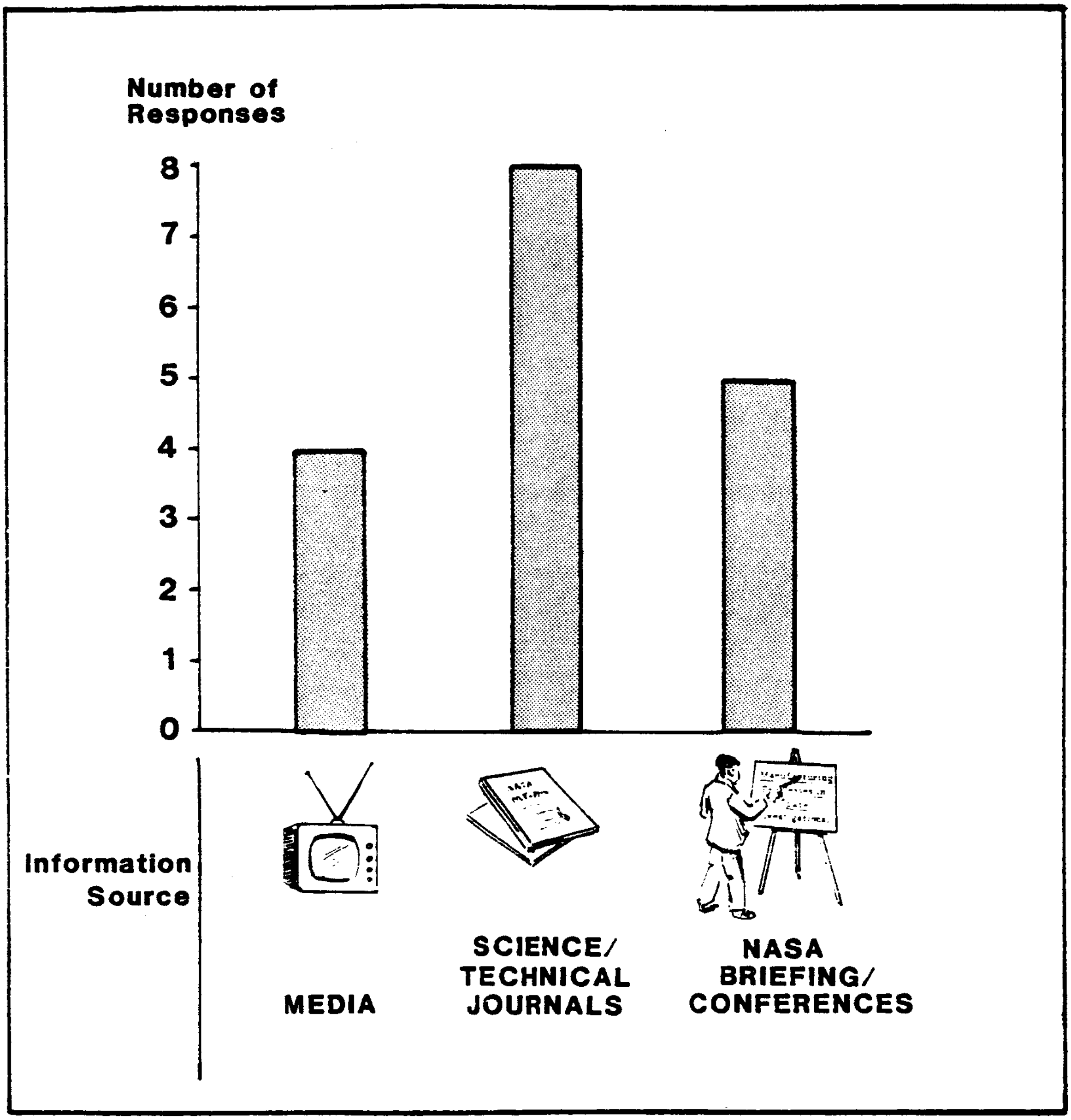
Table 10-19

Synopsis of Query Responses

Company Identification	Sales in Millions	Profit Margin as % of Sales	R & D as % of Sales	MPS Area of Interest	Sales Volume MPS Addressable (Millions)	Planning Horizon (Years)	Responsibility of Discussant	Is Space Opportunity Included in Company Plans?	Has Company Heard of MPS?	To What Extent is Company Aware of MPS?	Source of MPS Information	To What Extent is MPS Considered?	If Offered, Will Company Seek Space Opportunity?	In What Form Should MPS Opportunity Be Presented?	Is Company Interested in Further Pursuit of MPS?	Who Should Take the Next Step?	What Should Be the Next Step?	Will the Company Consider Further Steps?
A	4,300	■	■	Pharmaceuticals	1,100	2-3	Director of R & D	No	Yes	General	Scientific/ Technical Literature	Limited	Yes	Show Stimulating Results	Yes	NASA	Top-Level NASA Discussion	Yes
B	1,100	13	4.5	Medical Delivery System	300		Medical Planning Improvement & Innovation	No	Yes	General	Scientific/ Technical Literature	Limited	Yes	Stimulating Results	Yes	NASA	Presentation	Yes
C	6,100	8	1	Chemicals	2,000	2-3	Planning New Business Ventures	No	Yes	General	Scientific/ Technical Literature	Limited	Yes	Specific Results	Yes	NASA	Presentation	Yes
D	■	■	■	Aluminum	■	1-2	Director of Research	No	Yes	General	Scientific/ Technical Literature	Not Considered	Yes	Specific Results	Yes	NASA	Presentation	Yes
E	■	■	■	Brass & Aluminum Castings	■	1-2	Director of R & D	No	Yes	Limited	Scientific/ Technical Literature	Not Considered	Yes	Propose Specifics	Yes	NASA	Presentation	Yes
F	3,600	8.6	2.0	Chemicals	2,500	10	Head R & D Laboratory	Yes	Yes	General	NASA Conference	Limited	Yes	NASA Brief	Yes	NASA	Presentation	Yes
G	4,100	5.5	5.1	Electrical Components	1,600	12	Research Manager Advanced Technology	Yes	Yes	Limited	Media & Journals	Need More Information	Yes	NASA Brief	Yes	NASA	Seminar at Company	Yes
H	1,100	5.7	2.3	Telecom-munications Equipment	1,100	15	Responsible for Space Applications	Yes	Yes	Limited	Technical Journals	Limited	Yes	NASA Briefings	Yes	NASA	Briefing	Yes
I	34,400	23.0	6.1	Materials	150	15	Long-Term Research, Materials	Yes	Yes	Limited	NASA Spin-off Conference	Limited	Yes	NASA Symposium	Yes	NASA	Symposium	Yes
J	25,600	10.4	6.4	None as yet	200	10	Manager Advanced Programs	Yes	Yes	Limited	NASA Spin-off Conference	Limited	Yes	NASA Seminar	Yes	NASA	Seminar	Yes
K	280	17.9	Limited	None as yet	■	10	Assistant to President	Yes	Yes	Limited	Media	Limited	Yes	NASA Advise	Yes	NASA	Information	Yes
L	458	5.7	2.0	None as yet	■	5	Director Business Development	No	Limited	Limited	Media	Limited	Probably Not	Not Interested	No	NASA	Not Interested	No
M	3,100	-2.5*	3.1	Materials, Laminates, & Polymers	542	10	Materials Research	Yes	Yes	Works Closely With Company in MPS	Journals & Conference	Limited	Yes	Via Grumman	Yes	NASA	Not Interested	Yes
N	2,980	-2.8**	Limited	Materials	■	4	Research on Aluminum	No	Yes	Limited	NASA Brief	Limited	← No Interest →					
O	117.8	6.0	5.0	Advanced Materials	½	5	General Technology	No	Limited	Limited	Media	Not Relevant	Probably Not	Not Interested	No	NASA	None	No
P	5-10	Barely +	40	None	■		Director Genetic Engineering	Yes	Yes	Considerable	NASA Brief	Yes	Yes	NASA Brief	Yes	NASA	Brief	Yes

* Figures Quoted for 1982, +5.8 in 1981
** Figures Quoted for 1982, + 7.6 in 1980
■ Information withheld

PRIMARY SOURCES OF MPS AWARENESS



Number of responses to each information source.

Figure 10-1

Response Profile

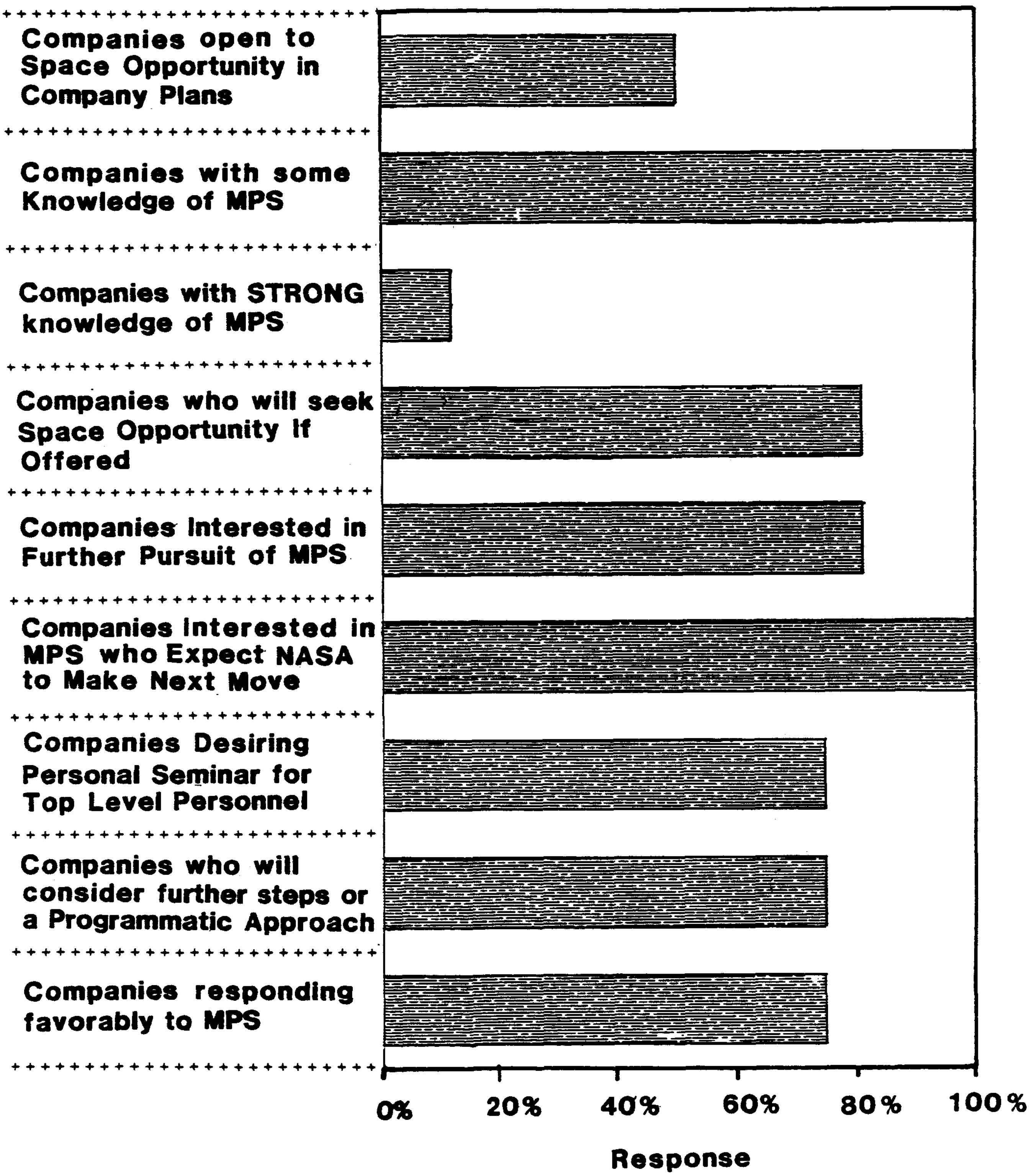
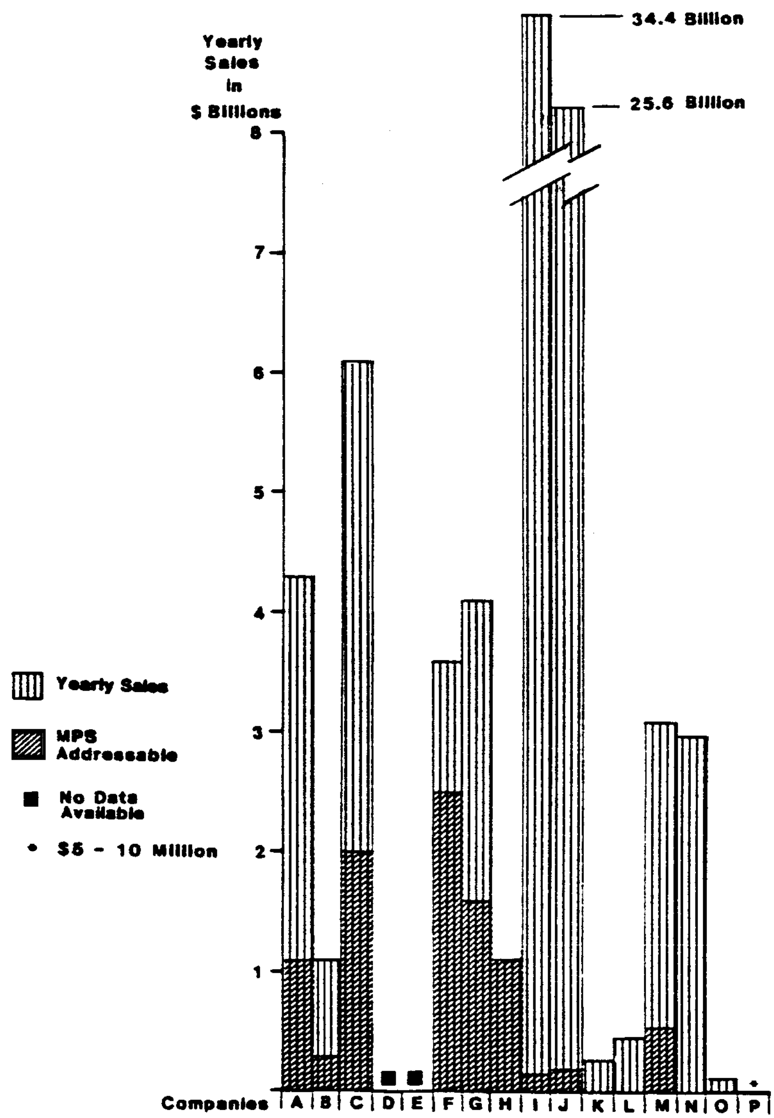


Figure 10-2



MPS MARKET

Addressable Sales Over Total Yearly Sales

Figure 10-3

10.6 Principal Products Addressable by MPS

This question portion of the survey form was intended to illuminate each company's primary area of interest within the realm of MPS investigations. From the responses, two areas of interest predominate: composite/materials and pharmaceuticals.

Six of the sixteen companies interviewed expressed a potential interest in composites or materials and three indicated an interest in pharmaceuticals or chemicals. Three of the remaining companies were uncertain as to which was their area of potential interest; one respondent expressed no interest in MPS; three companies indicated preferences in medical delivery systems, electrical components and telecommunication equipment respectively (see Figure 10-4).

10.7 Planning Horizon

Planning horizon represents each industry's allowable time between the inception of a program and the initiation of sales from that program. The planning horizon varies as a function of whether the program is Development oriented or Research oriented.

Development oriented companies are mainly concerned with near-time production. Their objective is to find new processes to increase short-term productivity or to improve quality in their current product line. Their planning horizon generally encompasses from two to three years.

Research oriented companies are geared toward discovering new products. Their objective, therefore, is to realize quantum, long-term improvements in processing or technology. A planning horizon lasting up to ten years or more is typical of these companies.

Figure 10-5 illustrates the planning horizons of the queried companies.

10.8 Comments and Concerns of Queried Companies

Industrial expectations of NASA's role in MPS may be derived from a series of interviews and presentations with selected representatives of industry. The recommendations formulated by the companies interviewed were that NASA should provide the following, in approximate descending order of priority:

Response To Quieries On MPS Areas Of Interest

(16 Companies)

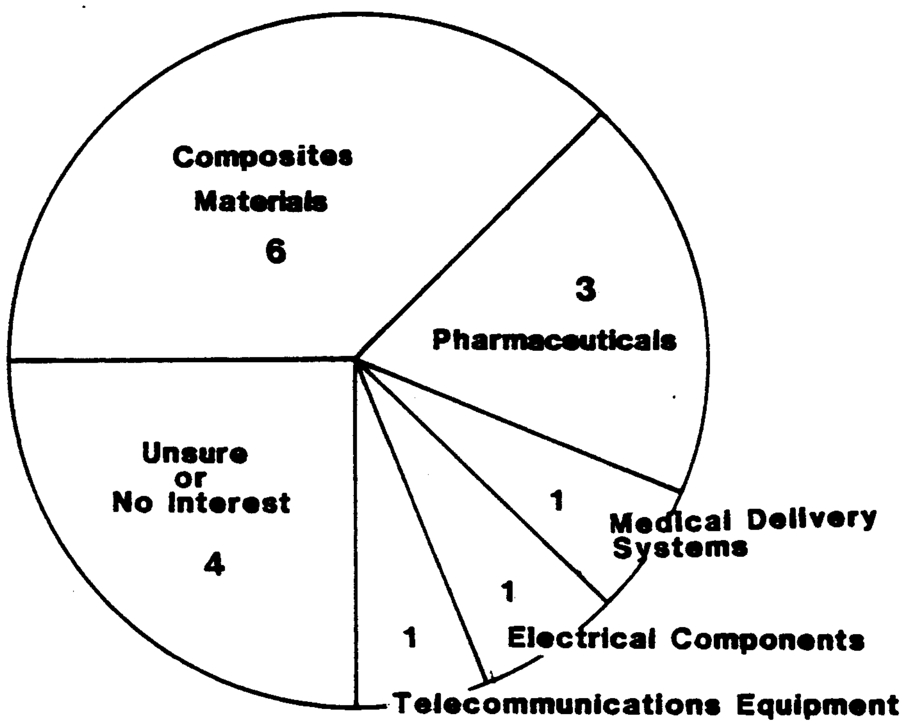


Figure 10-4

PLANNING HORIZON

(Years Predicted To Initiate Sales)

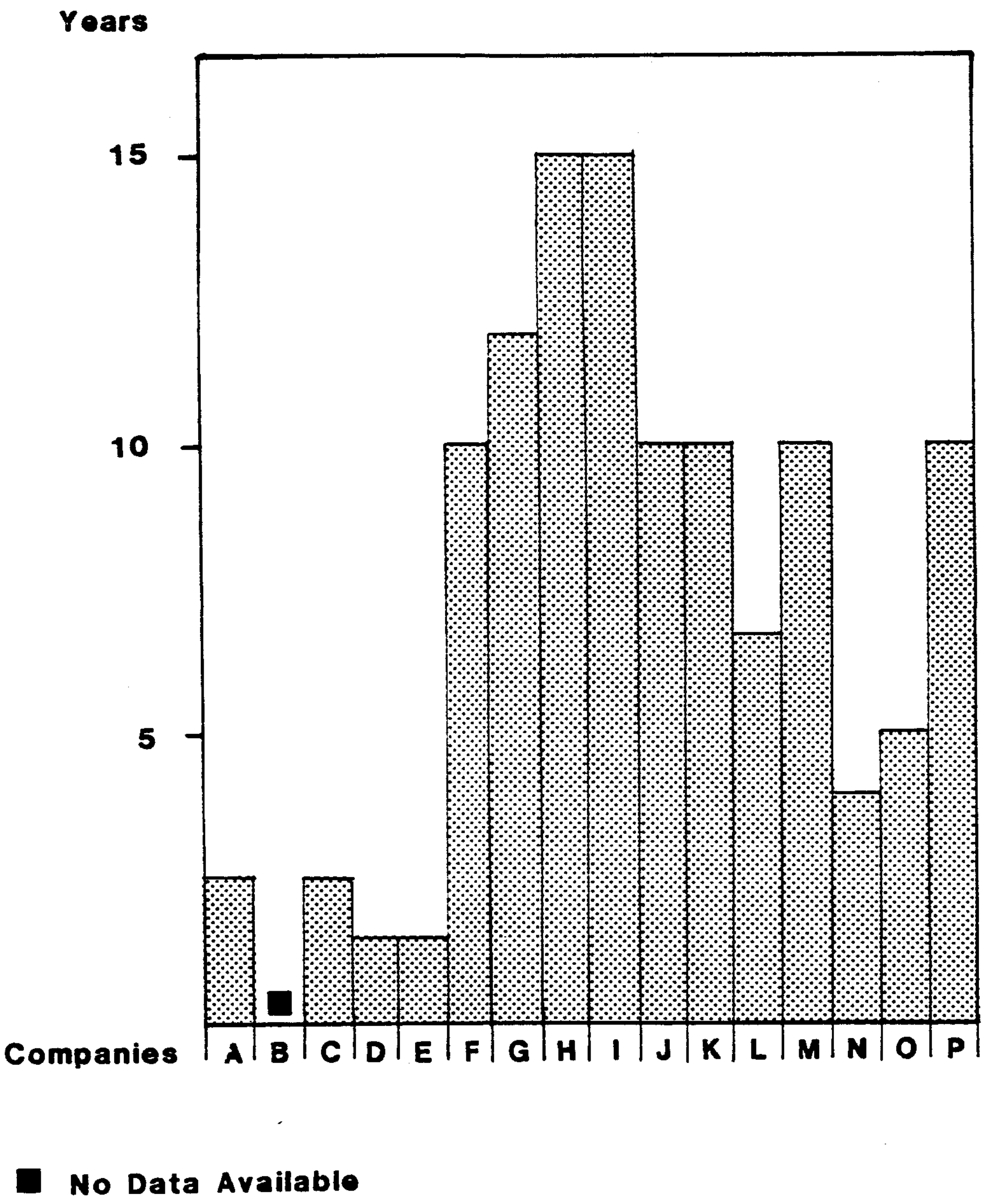


Figure 10-5

- specific examples of what materials processing in space can do. This includes physical principles, costs, case histories (for example the Johnson & Johnson electrophoresis), past accomplishments, technical and commercial histories of selected tests (who thought of it; how it started; how much is being spent by all parties concerned; future commercialization plans; etc.)

- specifics on the properties of space which could be used for MPS.

- a "road map" on how to access NASA persons to discuss interesting MPS ideas. The presenters indicated that for the moment the best road would be to contact ECOsystems.

- provide guidelines regarding the criteria which an industry must meet or satisfy in order to obtain NASA cost sharing. For example, must industry pay for astronaut time? Must industry pay for onboard electric power?

- a listing of the equipment already developed by NASA and available to perform flight experiments, including their capabilities, sizes, etc. This is in order to determine what is available and does not need to be duplicated.

- detail of what happens after a Shuttle-borne test becomes operational. Which would be the next test bed? How much would it cost? What are its characteristics and schedules?

- imagery of the inside of the Shuttle and of the available experimental cargo; also provide salient data on electric energy available, voltage, etc.

- guidelines for installation and configuration of fliable experimental equipment, including constraints posed by Shuttle.

- discussion on the schedule of Shuttle flights. A potentially significant problem is that the schedule of the Shuttle is not firm. A delay of 12 to

18 months, after an experimental program is designed and approved, would deter much of the industry, especially the industry working on applied research.

- a documentation of the Shuttle manifest for the next several flights or as far as possible in the future.

The general attitude of the audiences was that the material presented was substantially new, and that it stimulated further thinking about MPS.

10.9 Summary of Findings

Several key characteristics of potential constituent industries can be deduced from the survey:

- The individuals representing high-level technical, and new venture management companies are well versed in scientific matters.

- There is considerable knowledge and interest in the space effort among this high level management. However, it has little time available to explore the potential offered by the space program.

- High-level management is pressed to produce new technologies related to its products.

- It welcomes being apprised of new technological potentials, including the space potential.

- Application of the space potential should be focused on management's specific product, process or problem areas.

- Management would be willing to invest resources, (e.g., funds, skilled personnel) if real possibilities for tangible development could be perceived.

The net conclusion from these factors is a realization that NASA, if it is to foster the growth of space commercialization, must devote a concerted effort to clarifying these issues. This will require an orchestrated effort to work with potential constituent industries on the most promising areas of technological innovation in their particular problem areas, the potential application of space technology for these problem areas, and the development of new forms of experimentation. Potential constituents should be led into an involvement with the space commercialization effort in an orderly, well thought out manner. It is not sufficient to make presentations on the various space programs, e.g., STS or the availability of experimental facilities. The candidate industries should be fully apprised of all MPS scientific and engineering possibilities, the interest of NASA in trying to solve their problems, and NASA's willingness to work with them to establish sound experimental curricula tailored to their interests. A few visits and a sumposium or two will not induce industries to utilize the available NASA facilities, including STS flights. The need for an organized presentation is most critical when potential constituent industries are approached to participate in the Space Commercialization Program.

XI. CONCLUSIONS AND RECOMMENDATIONS

11.0 Conclusions

Major conclusions derived from queries of non-aerospace industry's perceptions of and interests in commercial operations in near-Earth orbit are as follows:

1. In general, industry responded favorably to the MPS Program and exhibited positive support for the commercialization effort.

2. Presentations and discussions brought to light that few companies, however, possess more than a basic understanding of MPS research.

3. R&D managers indicated that time constraints limited their capacity to think out the uses of space. As a result, they requested that more NASA research be directed toward their own particular areas of technological interest.

4. Concern for funding of commercialization efforts was secondary to industry's need to be thoroughly apprised of specific examples of successful MPS experiments germane to its areas of interest.

5. Industry expects NASA to take the lead in highlighting the advantages of the space environment for materials processing.

6. Proper follow-up efforts to initial queries are the key to obtaining industrys' committment to MPS commercialization.

Major conclusions concerning the MPS program are:

1. The MPS program lacks definite scientific goals and objectives.

2. A significant number of results of experiments conducted are inaccessible. Compounding this difficulty is that many of the PI's have moved and their forwarding addresses are no available.

3. Many of the available experimental results are couched in highly technical terminology requiring careful analysis to ascertain its impact on commercialization.

4. The majority of MPS experimental results to date are still in the research stage of development.

5. A complete compilation of experiments and results is needed for access by industry.

6. A number of useful apparatus have been developed for use in space experimentation which have application on Earth as well.

7. Total MPS experiment flight time to date (30 hours prior to the Space Shuttle era) is too short to serve as a solid base for the hard commercialization decisions that need to be made.

8. The electrophoresis of pharmaceuticals and manufacture of monodispersed latex spheres have current commercialization potential. In addition, ultra strong materials, "soft" magnets and immersible alloys appear to offer promise for commercialization.

11.1 Recommendations

The recommendations resulting from this report are as follows:

1. A centralized data source of MPS program results should be established.

2. These results should be cast in terminology accessible to industry.

3. A complete compilation of results should be used to stimulate industrial thinking and latent creativity.

4. A characterization and description of space experimental and processing apparatus should be included in commercialization endeavors.

5. The organized NASA space commercialization effort should be presented to potential space commercialization users with an emphasis on NASA's incentives for the use of the Space Transportation Systems and eventual use of the Space Station.

6. Since industry will expend time and money predominantly on the application of results which show definite promise of commercial utilization, NASA should concentrate efforts on MPS areas of experimentally proven promise and reduce efforts in those areas which show little immediate promise.

7. NASA should develop a well thought out process for attracting industries and fostering their involvement in the Space Commercialization Program. Figure II-1 is a schematic of how such a process could conceivably work. It is comprised of the following steps:

    a. Expose to Potential - This is accomplished through a variety of activities. For instance, the on-going efforts by the Office of Technology Utilization and Industry Affairs are performed on a one-to-one basis, using a technical presentation summarizing past space experimentation accomplishments and focusing on potential areas of application relative to the interests of constituent industries. Additional constituents may result from contacts made by other NASA offices such as STS, OSA; and, from focused technical meetings and other exchanges.

    b. Explore Interest - Once potential constituent industries are identified, and some interest or willingness to talk further are evidenced, a follow-up program should be pursued. Its intent, of course, is to further nurture the initial interest. At this stage, every effort should be made to understand the industry concerned, and to address its problem areas from both a technical and economic point of view. An informal agreement for further cooperation should be solidified.

COMMERCIALIZATION CONSTITUENCY BUILD-UP PROCESS

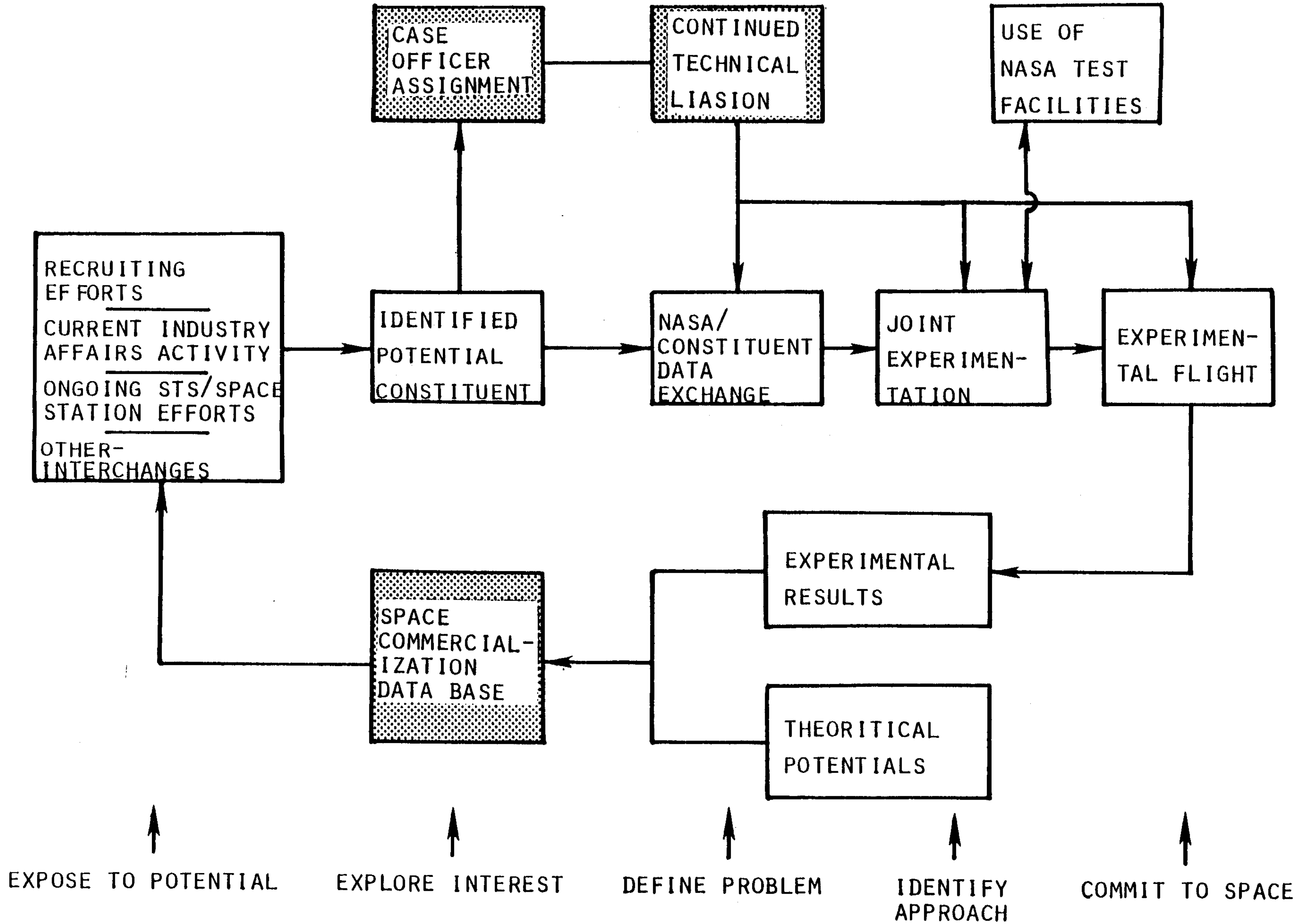


FIGURE 11 - 1

The assignment of a Case Officer or Liaison Personnel might be instrumental in bringing this and subsequent steps to a successful completion. Candidate industries would have access to specific contacts within NASA; meaningful exchanges between NASA and management would, presumably, be enhanced.

c. <u>Define Problems</u> - The third step requires a lengthy, in-depth technical exchange between NASA and the constituent industry. These exchanges should, in all probability, be conducted at a NASA laboratory and be tailored to the technological areas in which the industry in involved or interested. Specifically, the industry's level of technical expertise, current developmental progress, and future interests in specific scientific and/or technical topics, should be ascertained.

d. <u>Identify Approach</u> - Whereas the intent of step (c.) is to discover initial, common areas of interest and expertise, in step (d.) a joint scenario is investigated and planned. This mutually agreed-to approach should be as definitive as possible, including a clearly defined end-to-end program for experiments to be conducted on NASA facilities.

e. <u>Commit to Space</u> - This step is, of course, the culmination of the process and the final objective of the Space Commercialization program. Care must be taken, however, not to begin this Step until the results of step (d.) are thoroughly evaluated. Proof of concept, in this context, requires that industries witness a careful approach to flight through cautious pre-flight procedures.

8. Establish a process similar to the type discussed above, as a method for fortifying and demonstrating NASA's intention of establishing a Space Commercialization Program. This suggestion is made with the knowledge that the process could be exercised among a number of industries simultaneously, in order to determine its effectiveness. This might be initiated as part of the follow-up Tasks of the Office of Industrial Affairs Commercialization Contract.

APPENDIX A

SUMMARY OF MPS INVESTIGATIONS

This Appendix contains a summarization of 133 MPS-oriented experiments conducted between 1968 and 1980. The information was derived from existing published literature.

SUMMARY OF MPS INVESTIGATIONS

CATEGORY I

TITLE	INVESTIGATOR ORGANIZATION SPONSOR	VEHICLE	TIME FRAME	OBJECTIVE	DISCUSSION OF RESEARCH/RESULTS
Role of Gravity in Preparative Electrophoresis	Mr. R.S. Snyder MSFC Alabama 35812	Skylab		To review the current SOA in electrophoresis, with particular emphasis on the role of gravity and the use of istachophoresis.	The results so far obtained from the Apollo missions, and the Skylab demonstrations have clearly indicated the advantages of a low-g electrophoresis facility. The sharpness and self-restoring properties of boundaries in isotachophoresis make it an attractive candidate for space applications. This is most obvious from the comparison of the sharp boundaries obtained in the Skylab ex-experiment, as compared to the diffuse boundaries obtained in prior Apollo experiments (33,34).
Copper-Aluminum Eutectic	Mr. E.A. Haemeyer MSFC	Skylab		To show that an improved structure of lamellar eutectics could be grown in the absence of gravity induced thermal convection.	Specimens processed in zero gravity are superior to ground-base specimens on the basis of two characteristics: the defect spacing in lamellor widths is 12% better; the fault density is 20% less.
Electrophoresis Technology	Dr. R.E.Allen MSCF Dr. G.H.Barlow Abbot Labs	Apollo-Soyuz Test Project	1975	To demonstrate the feasibility of free-flow electrophoresis in a static column by using the low-g environment to suppress the convective mixing associated with joule heating.	Enhanced production of orokinase, erythropoietin, and granulocyte conditioning factors were found in the separate cell fractions, which hints that separation according to cell function was accomplished. One separation was of kidney cells. After they were fractionated in space the entire column was frozen to immobilize the separation and preserve the cells. When the frozen column was sliced on earth, the kidney cells of many fractions has maintained some viability.

CATEGORY I (continued)

Electrophoresis	Dr. K. Hanning Max Planck Institute for Biochemistry, Munich	Apollo-Soyuz Test Project	1975	To investigate and evaluate the increase in sample flow and sample resolution achievable in space.	Although there was a limited amount of data, there was an improvement in both the resolution and the throughput of continuous flow electrophoresis.
Composite Casting Experiment	I.C. Yates, MSFC	Apollo 14		To investigate the possibility of forming various composite materials with large density differences from the melt.	The space processed samples did not exhibit the separation of phase experienced by the ground control samples. However, the distribution of the dispersed phase was not as uniform as expected. The paraffin-sodium acetate mixture formed a fairly uniform in situ composite.
Exothermic Brazing	Mr. J.R.Williams Process Engineering Lab. Marshall Space Flight Center Alabama 35812	Skylab	June 12,13 1973	To evaluate brazing as a tube joining technique for the assembly and repair of hardware in space, and to study the spreading, mixing and capillary action of molten braze material in near zero gravity.	Brazing in space is feasible. The zero-gravity environment resulted in several differences: increased solubility, increased liquid spreading, more uniform monisci (liquid/vapor interface) and a reduction of braze alloy shrinkage defects.
Metal and Halide Eutectics	Dr. A.S. Yue U.C.L.A. Los Angeles, CA 90024	Skylab		To prepare fiberlike NaCl-WaF eutectic with continuous VaF fibers embedded in a NaCl matrix and to measure the relevant optical properties of space-grown and earth-grown eutectics.	Continuous NaF fibers were produced due to the absence of convection current in the liquid during solidification. Larger transmittance over a wider wavelength was obtained from Skylab grown ingots. This is due to excellent alignment of NaF fibers embedded in the NaCl matrix. Among the three samples grown in Skylab 3, no reaction between the NaCl-NaF eutectic sample and graphic container was detected. The original shape and length of the sample remained unaffected after resolidification in space.
Metals Melting	Mr. E.C.Mc Kannan MSFC	Skylab	June 1973	To study the behavior of molten metal; to characterize metals melted and	Electron beam welding, cutting and melting can be done in low-gravity.

	Alabama 35812		solidified in the low-gravity space environment; and to determine the feasibility of joining metals in space.	Solidification of specimens in a low-gravity environment were characterized by small, equiaxed grains in symmetric subgrain patterns.
Steady State and Segregation Under Zero Gravity InSb	Prof. A.F. Witt MIT Cambridge, MA 02139	Skylab	To confirm advantages of zero gravity environment; to obtain basic data on solidification; to explore the feasibilty of electronic materials processing in outer space.	It was established that ideal diffusion controlled steady state conditions, never accomplished on earth, were achieved during the growth of Te-doped InSb crystals in Skylab. Surface tension effects were found to establish non-wetting conditions under which free surface solidification took place in confined geometry. It was further found that, under forced contact conditions, surface tension effects led to the formation of surface ridges (not previously observed on earth) which isolated the growth system from its container. In addition, it was possible for the first time to identify unambiguously: the origin of segregation discontinuities associated with facet growth, the mode of nucleation and propagation of rotational twin boundaries, and the specific effect of mechanical-shock perturbations on segregation. The results obtained prove the advantageous conditions provided by outer space. Thus, fundamental data on solidification, thought to be unattainable because of gravity induced interference on earth, are now within reach.
Preparation of Silicon Carbide Whisker Reinforced Silver Composite Material in a Weightless Environment	Tomoyoski Kawada National Research Institute for Metals 2-3-12, Nakameguro Meguro-ku, Tokyo, Japan	Skylab	To obtain Ag and SiC whisker composites with high density and uniform distribution of whiskers by heating and pressurizing sintered products above the melting point of Ag in a weightless environment.	Skylab samples differed from the ground-based test sample, in uniform distribution of hardness values and the non-existence if any floating whiskers.

CATEGORY I (continued)

Vapor Growth of IV-VI Compounds	Prof. Wiedemeier Rensselaer Polytechnic Inst. Troy, New York 12181 c/o Dept. of Chemistry	Skylab		To establish the positive effects of microgravity on crystal growth and fundamental properties of the vapor transport experiments.	To confirm the unique conditions of weightlessness for materials processing and for the observation of basic transport phenomena. The analysis is based on a direct comparison of GeSe and GeTe crystals and of mass transport rate obtained in Earth and in space. The analysis of space and ground crystals is based on a comparison of deposition patterns, growth habits, optical and scanning electron microscopy of as-grown and cleaved crystal faces and thermal etching. The results demonstrate unambiguously a considerable improvement of the space crystals in terms of surface perfection, crystalline homogeneity and defect density. The observation of greater mass transport rates than expected in a microgravity environment is of basic scientific and technological significance. This indicates that conventional transport models are incomplete and demonstrates that crystals of improved quality can be grown at reasonable rates by this technique in space. These results are of practical improtance for the modification of crystal growth techniques on earth. The combined results confirm the unique conditions of weightlessness for materials processing and for the observation of basic transport phenomena.
Seeded, Containerless Solidification of Indium Antimonide	Dr. J.U. Walter University of Alabama in Huntsville Sponsor: NASA	Skylab	June 1973	To investigate the feasibility of containerless processing of single crystals in space; obtain information on such crystals; and demonstrate the potential of space for producing them.	Seeded containerless growth was demonstrated. Extremely flat surface facets were formed, which signifies that convectively induced perturbations were absent.

CATEGORY I (continued)

Monotectic and Sytectic Alloys	Dr. L.L. Lacy, MSCF Dr. C.Y. Ang, The Aerospace Corporation	Apollo-Soyuz Test Project	1975	Low-g environment was utilized by this experiment to minimize buoyancy and convective influences which in normal gravity prevent adequate synthesis of material systems in which significant specific gravity differences exist.	The liquid-state homogenization of polyary stalline, multiphase A/sb in low-g produces major improvements in macroscopic and microscopic homogeneity, showing 4 to 20 times less of the unwanted secondary phase than in l-g.
Crystal Growth	Dr. M.D. Lind Rockwell International Science Center	Apollo-Soyuz Test Project	1975	To investigate the growth of single crystals of insoluble substances by a process in which reactant solutions are allowed to diffuse toward each other through a region of pure solvent.	Some crystals were longer than gel-produced in l-g, some were plated-shaped and some were rhombohedral in shape. Birefringence was also exhibited by the low-g grown crystal of calcite. Since the reaction which produced these crystals did not go to completion, the investigator suggested that a longer reaction time or a higher temperature to increase the solubility of the reactants may result in larger crystals. The feasibility of the inter-diffusion of two chemicals to form a precipitate product, such as calcuim tartrate crystals grown in space, was demonstrated.
Halide Eutectic Growth	Dr. A. S. Yue et.al. UCLA	Apollo-Soyuz Test Project	1975	To study the growth of LiF fibers.	Fiber length in portions of the low-g samples showed a many-fold increase over their l-g fibers. Transmittance of the low-g fibers was reported to exceed that of the l-g fibers by several fold over most of the wavelength band 4 to 10 μm because of the better alinement of LiF fibers embedded in the $N_a$cl matrix. Fibers grown in space are aligned more regularly and are more parallel to the growth direction than those grown on Earth. Light can be seen to transmit farther through the space-grown sample than through the sample grown on Earth because of better alinement of the fibers.

CATEGORY I (continued)

Interface Marking in Crystals	Prof. H.C. Gatos A.F. Witt M. Lichtensteiger C.J. Herman, MIT	Apollo-Soyuz Test Project	1975	To determine crystal growth rate during the solidification process by utilizing a novel electric pulsing system to mark the interface. Other objectives included the determination of dopant segregation, investigation of possible non-gravitational convection phenomena, and the comparison of wetting phenomena between l-g and low-g.	In the postflight analysis, the investigators note that the Ge crystal slipped easily from the quartz tube, indicating that wetting did not occur in low-g, although in l-g wetting takes place. The investigators suggest that this wetting inversion in space-grown crystals may drastically reduce contamination of the melt by their confinement materials. The growth rates of the low-g and l-g crystals were virtually identical, assuming a value of about 9.5 um/sec after about 2.5 cm of growth. Development of a modified segregation theory, which considers the existence of initial growth rate transients, has been initiated by the investigators as a result of data obtained from this experiment. Dopant concentration increases steadily over about 1.5 cm from the regrowth interface but does not reach the anticipated steady-state prediction. This behavior is not fully understood, but it appears that asymmetrical thermal gradients arising from the three furnaces in the module are most likely responsible for the variations in growth rate and dopant distribution. The investigators insist, on the basis of their analysis of the dopant segregation and compositional homogeneity of the samples, that no time-dependent convective flows occurred in the Ge melts even though there was little or no contact between the melt and the container. This result illustrates the importance of establishing a thermal configuration, producing planar or near-planar solidification fronts to achieve radial compositional homogeneity during crystal growth under diffusion-controlled, near zero-g conditions.

CATEGORY I (continued)

Fluid Dynamics and Thermodynamics of Vapor Phase Crystal Growth	Dr. Herbert Wiedemeier Rensselaer Polytechnic Institute		Jan. 1980 To Dec. 1982	To provide basic mass transport and crystal growth data which, combined with a thorough knowledge of the thermodynamics, will improve the fluid dynamic characterization of vapor transport systems.	The crystals showed improved growth habit and surface features and lower defect density than those grown in a similar processor in a terrestrial environment. Dopant concentrations determined in space solely by diffusion-controlled processes were closely controlled. The results demonstrate more uniform growth in the absence of gravity-driven convection. Chemical vapor transport crystal growth rates are substantially higher than expected from extrapolation of laboratory data.
Kidney Cell Electrophoresis	Dr. Paul Todd Penn State Univ.		June 1980 Cont.	To repeat the MA-011 experiment under conditions which are optimum for the viability of human kidney cells and most favorable for the least possible electrophoretic separation of the few cells (about 5%) which produce urokinase or human granulocyte conditioning factor (HGCF), and erythropocintin.	Cells from cultures obtained from 26 commercially-prepared explants have been studied with respect to electrophoretic mobility distribution, growth in culture, and urokinase production. The testing of various electrophoresis buffers indicates that the low ionic strength required for effective electrophoresis in microgravity experimented compromises the viability of the cells. Procedures have been been established for urokinase assay of cultures derived from cells separated in microgravity experiments, which will take place in shuttle OFT-3 mission.
Electrophoresis Demonstration	Dr. R.S. Snyder MSFC	Apollo 14 Apollo 17		To test the concept of using low-g to prevent unwanted convective flows from Joule heating in static-column, free-flow electrophoresis, and to identify problems that may be encountered with bubble formation, nongravity-driven flows, and other possible problems that might be encountered in space electrophoresis.	Sample bands were severely distorted by electroosmotic flows in both experiments; however, the experiments provided the impetus to develop special coatings to lower the zeta potential and eliminate such flows in future experiments.

CATEGORY I (continued)

Sphere Forming	Dr. D.J. Larson Grumman Aerospace Bethpage, New York 11714	Skylab	During Skylab II	To study the effects of weightlessness in solidification processess.	There was an outstanding record of both initial and terminal solute redistribution processes. The last regions to solidify evidence extensive solification terracing.
Crystal Growth from the Vapor Phase	Dr. H. Wiedemeier et.al. Rensselaer Polytechnic Institute	Apollo-Soyuz Test Project	1975	To study the growth of semiconductor crystals by chemical transport reactions using a vapor transport agent in a low-g environment.	No difference was found in the lattice parameters and the orientation of the native growth faces of the crystals formed in low-g and l-g. The turbulent flow characteristic of l-g growth did not exist in the low-g environment. The low-g grown crystals have smoother surfaces and better defined edges. An average density of etch pits for the space-grown crystals was reported to be one or two orders of magnitude less than the crystals grown in l-g. As in the earlier M-556 experiment, the improvements noted in the structural and chemical homogeneity of the low-g grown crystals are attributed to the reduced convective turbulence and interference with the transport process. In addition to the confirmation of greater mass transport rates in low-g than predicted, the investigators suggest that the flux results indicate the existence of thermo-chemically induced convection in reactive solid-gas phase systems. They suggest that this "thermochemical" convection may be overshadowed by gravity-driven convection in l-g.
Zero-G Processing of Magnets	Dr. D.J. Larson Grumman Aerospace Corporation	Apollo-Soyuz Test Project	1975	To investigate the effects of reduction of gravitationally dependent elemental segregation and convection in the solidification of high-coercive-strength magnetic composites in low-g.	The array of MnBi crystals processed isothermally apparently resulted from edge-to-center gradients and produced no unusual magnetic effects.

CATEGORY I (continued)

					The directionally solidified flight samples showed a considerably different microstructure from the ground control samples. The Mn Bi rods were smaller in diameter and were circular in cross section rather than chevron-like. The coercive strength of the lattice parameter improved by approximately 60 percent.
Multiple Materials Melting (metals)	L.I. Ivanov,et.al. Institute for Metallurgy USSR	Apollo-Soyuz	1975	To utilize the low-g environment to reduce gravity-driven segregation effects in the synthesis of compound materials of significantly different specific gravity; to investigate the mutual diffusion and formation of intermetallic phases as a result of the interaction of a meltable matrix (Al) and hard, refractory inclusions (W).	The kinetics of diffusion and phase formation in the solid W (WRe alloy) liquid A l diffusion area was approximately the same for both ground base and flight samples. This conclusion was suggested by the similarity in geometrical characteristics of the the diffusion layer constituents which they observed. The low-g diffusion and phase formation processes for the W-Al, however, were reported to exhibit several differences from the W-Al-Re system. In the binary system, the WAl_5 phases are thinner than in l-g, are needle-shaped, and have a lower distortion angle; the WAl_{12} phase has a crystalline faceting. In the case of the tertiary system, the distinguishing features were reported to include a higher porposity at the diffusion layer/WRe alloy interface, and the formation of phases rich in Al. The CuAl eutectics and powdered Al low-g samples showed no appreciable difference from their Earth-processed counterparts according to the investigators. Melting of the powdered Al suggested to the investigators that slight excess of temperature above the Al melting point reduces the possibility of individual particles being fused together in a low-gravity orbital environment.

CATEGORY I (continued)

The Upgrading of Glass Microballoons	Dr. Stanley A. Dunn Bjolksten Research Labs	August 1978 To August 1982	To study extensively the processes and mechanisms involved in producing glass microballoons of acceptable quality for laser fusion by gas jet levitation and manipulation in the molten condition.	An important technique is being developed for producing CHSs of virtually any degree of fineness and aspect ratio (hole length to effective hole diameter). Whereas optimum levitating stability requires larger aspect ratios of the order of 10 and above, most small hole drilling techniques are limited to values of 3 or 2 below. The essence of the subject technique rests upon the discovery that holes of noncircular cross sections may perform quite as satisfactorily as circular. The CHS by this technique consists of a symmetrically packed and confined bundle of uniformly sized wires.
HgI_2 Crystal Growth for Detectors	W.F. Schnepple Dr. L. Vandenberg EG&C Corp. Santa Barbara, CA.	April 1978 To April 1983	To obtain a benchmark quality sample grown at low-g conditions and to study vapor growth phenomena under space conditions.	Ground-based crystals show a defect structure which impairs their performance as nuclear radiation detectors. These defects may be caused by the gravitational force acting on the crystal in its weakened state at the elevated growth temperature and by irregular convection patterns in the vapor during growth. Mechanical strength measurements were performed (uniaxial compression tests) which show that the crystals exhibit slip parallel to the c-planes at stresses as low as 10 psi. Preliminary calculations using a simple linearized model indicate the oscillating instabilities in the convection part of the vapor transport system are unlikely, even at 1 g, provided that the utmost care is taken in the preparation of the crystal growth source material.
Directional Solidification of Magnet Composition	Dr. R.G.Pirich Grumman Aerospace Corporation	Feb. 1977 to Feb. 1983	To investigate the finer microstructure and enhanced magnetic properties of Ma-Bi eutectic directionally solidified in space.	Morphological analyses of eutectic Bi/Mnbi samples that were directionally solidified during the 240-s low-g interval

CATEGORY I (continued)

					of the SPAR VI flight experiment show statistically smaller interrod spacings and rod diameters when compared to samples grown under identical solidification furnace conditions, in the same apparatus, in l-g. The magnetic property measurements indicate that the flight samples contain ~ 7 v/o less dispersed MnBi than similarly processed l-g samples for the same starting composition. Convectively driven temperature fluctuations in the melt, which result in unsteady liquid-solid interface movement in l-g, are suggested to explain the morphological change between log-g and l-g solidification. As a result of these fluctuations, an adjustment between the interrod spacing, growth velocity, and total undercooling at the solidification interface is proposed to account for the observed change in volume fraction of dispersed MnBi. Future low-g experiments involving both eutectic (SPAR IX) and off-eutectic (SPAR X) compositions are planned to quantify these unusual low-g effects.
Germanium Silicon Solid Solutions	U.S.Zemskov et.al. Institute for Metallurgy USSR	Apollo Soyuz	1975	To study the possibility of using microgravity conditions for obtaining solid solution monocrystals with uniformly distributed components.	The crystallization in low-g did not occur under the expected ideal stationary growth and segregation conditions because all flight samples melted completely. Convective mining was negligible in the low-g and graphite ampoule walls were not wet by the molten samples.
Preparative Electrophoresis of Living Lymphocytes	Dr. C.J. van Oss State Univ. of NY Buffalo 14214	Skylab		To develop the methodology for electrophoretic cell separation in space by first working out a methodology at gravity=1.	Both descending and ascending electrophoretic lumphocyte separation at gravity=1 show the possibilities as well as the probable limits to lymphocyte electrophoresis on earth.

CATEGORY I (continued)

					Samples that contain 1-2 X 10^6 human lymphoeytes were separated into T-cell rich factions containing up to 96% T-cells after 1 hour of electrophoresis, as judged by immunofluorescence. Distinct bands of cells were not distinguishable at the conclusion of the electrophoresis. The slowest fractions were enriched 57% in B-cell content (which is not sufficient to use this method to yield purified B cell fractions).
Marangoni Effect in Crystal Processing	Dr. Arthur Fowle A.D. Little Cambridge, MA Dr. A.F.Witt MFT	Skylab	March 1978 To Dec. 1980	To measure the freezing interface morphology and the velocity and temperature fields on the surface of a molten zone in a cylindrical sample of gallium doped germanium in a crystal growing configuration.	
III-V Semiconductor Solid Solution Single Crystal Growth	Dr. E.R. Gertner Dr. M.D. Lind Rockwill International Downey, CA		April 1979 To Dec. 1980	To improve the quality of semiconductor substrate material used in epitaxial growth processes, since the quality of the epitaxial deposit is often limited by the quality of the substrate.	The research objective was to generate a compositionally homogeneous seed for future float zone experiments. However, technical difficulties with the original approach and recent advances in the vapor growth of III-V solid solution led to a reassessment of the initial approach and a redirection of the program to the single crystal growth of CdTe, a II-IV compound.
Containerless Processing of Glass Forming Melts in Space	Dr. D. E. Day University of Missouri-Rolla		Feb. 1982 To Jan. 1983	1) To measure the effectiveness of containerless melting in extending the compositional limits for glass formation	
Solution Growth of Crystals in Zero-Gravity	Dr. R.B. Lal Alabama A&M Univer. Dr. R. L. Kroes MSFC	Possible Space Lab 3	June 1978 To June 1983	1) to grow TGS crystals from aqueous solution in low-gravity 2) to investigate mass transport and heat flow in a diffusion-controlled growth system, and	Single crystals of TGS were grown using a conventional low temperature solution growth method and the growth process was extensively characterized. Also, a unique

CATEGORY I (continued)

			3) to evaluate the feasible advantages and technical potential of producing solution growth crystals in space.	technique of growing solution growth crystals by extracting heat at a programmed rate from the crystal through a semi-insulating sting was developed. TGS crystals will be grown by this technique during the Spacelab 3 Mission. Data on heat and mass transport in a diffusion-controlled system will be obtained using a laser holography technique. Analytical studies are underway to estimate growth rates in low-g conditions.
HgI_2 Crystal Growth for Nuclear Detectors	W. F. Schnepple Dr. L. Vandenberg EG&G, Inc.	April 1978 To April 1983	Ground-based crystals show a defect structure which impairs their performance as nuclear radiation detectors. These defects may be caused by the gravitational force acting on the crystal in its weakened state at the elevated growth temperature and by irregular convection patterns in the vapor during growth. The objectives of this program are to obtain a benchmark quality sample grown at low-g conditions and to study vapor growth phenomena under space conditions.	Mechanical strength measurements (uniaxial) compression tests) show that the crystals exhibit slip parallels to the c-planes at stresses as low as 1/2 psi. Preliminary calculations using a simple linearized model indicate the oscillating instabilities in the convection part of the vapor transport system are unlikely, even at 1-g, provided that the utmost care is taken in preparation of the crystal growth source material.
Solution Growth of Crystals in Zero-Gravity	Dr. R.B. Lal Alabama A&M University Dr. R.L. Kroes, MSFC	To June 1983	To grow TGS crystals from aqueous solution in low-gravity; to investigate mass transport and heat flow in a diffusion-controlled growth system; to evaluate the possible advantages and technical potential of producing solution growth crystals in space.	Single crystals of TGS were grown using a conventional low temperature solution growth method and the growth process was extensively characterized. Also, a unique technique of growing solution growth crystals by extracting heat at a programmed rate from the crystal through a semi-insulating sting was developed. TGS crystals will be grown by this technique during the Spacelab 3 Mission. Data on heat and mass transport in a diffusion-controlled system will be obtained using a laser holography technique. Analytical studies are underway to estimate growth rates in low-g conditions.

CATEGORY I (continued)

Homogeneous Crystallization Studies of Glass Forming Systems	Dr. E.C. Ethridge Dr. P. Curreri Marshall Space Flight Center		April 1981 To April 1984	To use containerless as well as pseudo-containerless processing techniques to melt and resolidify borderline glass formers in such a way as to obtain critical cooling rates to avoid homogeneous crystallization	
Acoustic Chamber Processing	Dr. T.G. Wang Jet Propulsion Laboratory	Skylab		To describe an acoustical method that can control any molten material within a container in a space environment.	By readily levitating, positioning, and manipulating materials placed in it, the acoustical resonator can serve a variety of space processing operations, such as drawing crystals, degassing and stirring of melts and castings.

SUMMARY OF MPS INVESTIGATIONS

CATEGORY 2

TITLE	INVESTIGATOR ORGANIZATION SPONSOR	VEHICLE	TIME FRAME	OBJECTIVE	DISCUSSION OF RESEARCH/RESULTS
Heat Flow and Segregation in Directional Solidification	Prof. Witt MIT			To optimize crystal growth and segregation during solidification in Bridgman-type configurations.	Making use of interface demarcation and spreading resistance analyses, it was found for conventional thermal geometries that, at constant ampoule lowering rates, both growth and segregation remain non-steady state for growth lengths of up to 6 cm. The rate of growth is significantly less than the lowering rate under high thermal gradient conditions but exceeds the lowering rate by a factor of two at low applied thermal gradients. Upon temporary arrest of ampule lowering, uncontrolled growth or back melting takes place depending on the magnitude of the existing axial thermal gradient. The experimental evidence obtained suggests that conventional vertical Bridgman configurations cannot provide a thermal environment in which steady state crystal growth and radially uniform dopant segregation are achievable. To arrive at an improved Bridgman-type configuration suitable for growth on earth and in reduced gravity environment, it was decided to base the system design on one-and two-dimensional heat transfer analyses. These calculations suggested the use of aligned heat pipes separated by a gradient zone region with variable heat transfer characteristics. Such a system has now been constructed and is in the process of being characterized for thermal and growth characteristics.

				With the establishment of thermally stabilized growth conditions in vertical Bridgman configuration, it became possible to study dopant segregation at solidification rates ranging from 0.5 to 15 m/s. This study revealed that the basis for all generally accepted segregation theories, at constant and rate dependent interface distribution coefficient which is identical with the equilibrium distribution coefficient, does not apply to the system germanium-gallium. It was found that during both faceted and nonfaceted growth the interface distribution coefficient differs from k_o and in the growth range from 0-2 m/s exhibits a pronounced rate dependence. This finding is of fundamental importance to space processing since this particular system has been and is extensively used for the characterization of growth in a reduced gravity environment.
Convection in Grain Refining	Prof. J. Szekoly Prof. M.C. Flemings MIT	I	To obtain a better understanding of the relationship among fluid flow phenomena, nucleation, and grain refinement in solidifying metals both in the presence and in the absence of a gravitational field. An ultimate technical aim is to determine ways to achieve significant grain size reductions in hard-to-process melts and significant property refinement by obtaining solidification under highly non equilibrium conditions..	A brief summary of results obtained to date is the following: (1) nickel base alloys samples of approximately 1 gram have been successfully levitated, in inert atmospheres undercooled by amounts up to 270^{0}C, and a wide range of grain sizes and solidification structures obtained, depending on amount of undercooling and cooling rate; (2) two important innovative techniques have been developed to obtain large amounts of undercooling in high temperature (iron, nickel, and cobalt) alloys. In one of these, the metal is melted and then "emulsified" (sitrred into fine droplets) in a finely crushed oxide or salt. In the second, small pre-alloyed metal droplets are interspersed at room temperature with finely crushed oxide or salt. The admixture is then melted; (3) extremely large under-

					coolings have been obtained in the above two methods because of the fine particle size and cleansing action of the slag; (4) emphasis of the experimental work at the present time is on increasing amounts of undercooling obtainable, and therefore the types of structures obtainable through (a) use of alternative emulsification media, (b) increasing rate of heat extraction, and (c) process variations; (5) a computational capability has been developed to determine the electromagnetic force field, the fluid flow field and the temperature field in induction stirred systems, including contained cylindrical metals and levitated spherical melts; (6) calculations were carried out for a variety of conditions, including heat and fluid flow in a metal held in an inductively stirred cylindrical crucible and levitation melted specimens both on the ground and in a zero gravity environment. (7) calculations have shown that the fluid flow field is markedly different for ground based and for zero-gravity conditions: and, (8) the techniques developed for solving MHD type problems in molten metal and glass systems and the results generated are thought to have made an important contribution to this overall field. The foregoing results of this research have implications both for study of convection at zero-g and for potential engineering application, both at 1-g and at zero-g. As noted before, enormous undercoolings have been obtained at 1-g and and greater undercoolings were anticipated under microgravity conditions.
Comparative Alloy Solidification	Dr. M.H. Johnston MSFC	Aircraft KC-135	1980	To use transparent model systems in order to investigate the gravitational in-	A striking decrease in grain size with increasing g-field was demonstrated, confirm-

CATEGORY 2 (continued)

				fluence on the solidification process of actual metallic systems	ing earlier predictions that dendrite multiplication was influenced by gravity-driven convection flows. In the low-gravity solidification of the SN-15wt%Pb alloy, the grain orientations were found to be completely isotropic, indicating probable nucleation in the center of the molten liquid. A significant increase in dendrite arm spacing was noted in the low-g metal sample, thus substantiating earlier results from the metal model systems. A tin-3wt%Bi alloys was solidified on a second flight. This had a few very large grains in constrast to the very fine grained ground based samples. Further studies of this phenomena were carried out on the KC-135. A sample was partially solidified in low-gravity and then solidification was completed during the high-g pullout. The transition in the grain structure was rapid.
Electrophoretic Separation Based on Immunomicrospheres	D. A. Rembaum Jet Propulsion Laboratory California Inst. of Technology Pasadena, CA	Space Flights	1978 Continuing Task	To demonstrate a new concept for cell separation based on labeling specific groups of cells with immunomicrospheres and isolating the labeled cells and unlabeled cells by means of electrophoresis; and, to demonstrate that the cell separation of immunologically labeled cells is more efficient in the space environment than Earth.	By choosing microspheres of a mobility at least 20% lower than that of the target cell, it was possible to electrophoretically separate human B and T lymphocytes, a separation which is impossible without immunomicrospheres. This type of separation should be considerably improved in the absence of gravity.
Solidification of Liquid Miscibility Gap Alloys Under Free Fall	Dr. L.L. Lacy MSFC Dr. G. Otto University of Alabama in Huntsville	Drop Tower Experiment		To investigate the solidification of alloy systems that exhibit a liquid phase immiscibility gap.	Fine uniform dispersions of Ga-rich particles in a Bi matrix, obtained in the freefall solidification samples solidified under normal gravity, exhibit mass separation between the Bi and Ga. The unique microstructure obtained by low-g

CATEGORY 2 (continued)

				solidification caused the resistivity of the sample as a function of temperature to exhibit a unique behavior.
Influence of Gravity-Free Solidification on Microsegregation in Germanium	Dr. J.T. Yue Texas Instruments, Inc. Dallas, Tx. 75222	Skylab #2	To characterize the influence of gravity-free solidification on the microsegregation of a semiconductor material.	1) The solute boundary layer at the growth interface in space is correspondingly thinner. The solidification interface is significantly smoother and is found to be initially convex toward the melt into space. Microsegregation caused by growth rate fluctuations was eliminated, which improved uniformity from recrystallization in space. Accordingly, it may be feasible to grow higher composition alloy semiconductors from the melt, as mercury cadmium telluride and lead tin telluride, without the interfacial breakdown that accompanies uncontrolled growth rate fluctuations, under conditions that reduce defect density due to the growth process.
Silver Grids Melted in Space	Prof. E. Aernoudt Catholic Univ. Leuven, Belgium	Skylab	To make a preliminary study of the behavior of porous material when melted and resolidified in weightless condition. When only part of a solid body is melted in zero gravity, the tendency of the molten part to become spherical may be restricted.	1) Original porosity disappeared during the melting stage. 2) Even if samples were perfectly spherical in the liquid state, their shape is altered on solidification. 3) Leveling out of impurity concentration gradients appears to be slow in molten metal when gravity induced convection is absent. 4) When only part of a solid body is melted in zero-gravity, the tendency of the molten part to become spherical may be restricted. Skylab samples differed from the ground-based test sample, in uniform distribution of hardness values and the nonexistence of any floating whiskers.

CATEGORY 2 (continued)

Studies of Liquid Floating Zones	Dr.J.R.Carruthers Bell Laboratories Murray Hill, NJ 07974	Skylab II		To examine the stability constraints imposed on the liquid zone in zero gravity so that crystal growth and purification processing methods may be developed for preparation of reactive material in future space flights.	The stable behavior of extended liquid floating zones was demonstrated.
Immiscible Alloy Compositions	Mr. J.L. Reger TWR Systems Group Redondo Beach, CA 90278	Skylab		To thermally process ampoules containing materials exhibiting either liquid or solid state immiscibility in order to determine the possibility of bulk production in space.	Low gravity processed specimens exhibited better homogenization and microstructural appearances than the one gravity control specimens. The electronic behavior of the low gravity specimens were equal or superior in every respect and the Ampoule B specimens exhibited an anomalous superconducting transition temperature approximately 2 K higher than either the elements or the one gravity control specimens. In addition, the low gravity processed A and B ampoules exhibited X-ray diffraction lines not identifiable with any referenced diffraction patterns. It is concluded that low gravity processing of materials processing liquid or solid immiscibility can produce compositions exhibiting unusual metallographic and electronic behavior.
Capillary Wicking	A.F. Whitaker MSC	Apollo-Soyuz Test Project	1975	To illustrate wicking action in a weightless environment and to determine the efficiency of transfer and wicking rates of stainless steel wicks used for fluid management in spacecraft.	Wicking of both oil and water proceeded much faster in the ASTP than anticipated on the basis of ground tests and KC-135 flight tests. The liquid was observed to rise along the corner formed by Teflon support back and mesh. Since Teflon is not normally wetted by the fluids used, this behavior was unanticipated.

CATEGORY 2 (continued)

Monotectic and Sytectic Alloys	Dr. L.L. Lacy, MSCF Dr. C.Y. Ang, The Aerospace Corporation	Apollo-Soyuz Test Project	1975	Low-g environment was utilized by this experiment to minimize buoyancy and convective influences which in normal gravity prevent adequate synthesis of material systems in which significant, specific gravity differences exist.	The liquid-state homogenization of polyary stalline, multiphase A/sb in low-g produces major improvements in macroscopic and microscopic homogeneity, showing 4 to 20 times less of the unwanted secondary phase than in l-g. Diffusional and liquid-state homogenization analyses indicate that gravity-induced convection can severely complicate the homogenization of l-g melts, inducing compositional and microstructural inhomogeneity during solidification. Other unique binary systems which are difficult to synthesize on Earth because of gravity-induced effects may be advantageously processed in space.
Epitaxial Growth of Single Crystal Films	Dr. M. David Lind Rockwell International Dr. R.L. Kroos, MSFC	SPAR	Oct. 1975 To May 1980	To grow exitaxial films of gallium arsenide by liquid phase epitax p(LPE) in low gravity and to compare them with films grown in normal gravity.	Epitaxial films of reasonably good quality and very nearly the thickness (1 um) predicted for convection-free, diffusion-limited growth were produced.
Studies of Model Immiscible Systems	Dr. L.L. Lacy Marshall Space Flight Center	Ground	Oct. 1979 To Oct. 1981	To use model organic immiscible systems to obtain fundamental information applicable to materials of interest in the Materials Processing in Space program in order to interpret results of flight experiments involving monotectic alloys.	Immiscible liquids remained in a dispersed state for over 10 hours after mixing in a low-gravity environment.
Countercurrent Distribution of Biological Cells	Dr. D.E. Brooks Univ. of Oregon Health Sciences Center		Nov. 1979 To Nov. 1982	To develop and understand cell partition in a reduced gravity environment, as a sensitive, analytical and high resolution preparative procedure for biomedical research.	It was found that phase separation, as indicated by optical cleaning, occurs rapidly under the influence of a modest electric field, but that turbidity then reappears after a few minutes. By isolating the upper and lower halves of the sample chamber at different times after mixing, in the presence or absence of an

CATEGORY 2 (continued)

					electric field, it was found that most of the phase separation occurs before a large change in turbidity is detected, implying that the optical signal is dominated by the haze of small drops left behind after the bulk of the phase volumes have separated. The direct sampling experiments have demonstrated unequivocally, that low electric fields (~ 0.5 v cm^{-1}) enhance the rate at which the phases separate, even in the presence of unit gravity.
Crystal Nucleation in Glass Forming Alloy and Pure metal Melts Under Containerless and Vibrationless Conditions	Prof. David Turnbull Harvard Univ.	Drop-Tube	June 1978 To Dec. 1982	To characterize nucleation behavior in glass-forming alloy melts. Such experiments should indicate whether formation of alloy glasses in bulk form is possible, and, if so, the necessary conditions for their formation.	It was found that the onset undercooling, ΔT_o, for copious nucleation in molten Au_4Si droplets varies widely with thermal treatments which alter the nature of the SiO_2 film on the droplet surface. However, ΔT_o as large as 1/3 of the liquidus temperature for some droplets was observed. Glass and crystallization temperatures of Au_4Sibased alloys are sharply increased ($\sim 1^o$ per atom %) when Cu replaces some of the Au. The transient period for crystal nucleation has been shown to be important for glass formation in alloys, such as these, with low reduced glass transition temperatures. Drop tube experiments are being performed with droplets of Pd-Si and some Fe-based-glass forming alloys. Analysis of the crystallization shows that crystal nucleation occurs in the droplet surface and is influenced by the atmosphere in the drop tube (especially moisture).
Surface Tension-Driven Flow in a Weightless Fluid	Dr. S. Ostrach Case Western Reserve University	Drop Tower		To obtain experimental data on surface-driven convection in the absence of gravity-driven flows.	Surface tension-driven flows can induce significant convection in a low-g environment.

CATEGORY 2 (continued)

Heat Flow and Convection Experiment	T.C. Banmister MSFC Dr. P.G. Grodzka, Lockheed	Apollo 14 Apollo 17	I) To determine to what extent contributions from residual vehicle accelerations and nongravity-driven convection affect heat transfer 2) to dramatize the fact that convective flow can occur in the absense of gravity 3) to study the onset of unstable surface tension-driven convection in the absence of buoyancey-driven convection.	On Apollo 14 the heat flow was 10 to 30% greater than predicted, which was due to crew-induced disturbances. On Apollo 17 heat flow agreed with predictions based on pure conduction.
Radioactive Tracer Diffusion	Dr. A.O.Ukanwa Howard University Washington,D.C. 20001	Skylab #3 1973	To determine, in a convection-free environment, the self-diffusion coefficients for zinc and to estimate the reduction in convective mixing in Earth gravity by going into the zero-gravity environment of space.	An equation was determined for a self-diffusion coefficient in liquid zinc. Complications arising from convection in liquids during mass transfer on earth may be avoided or minimized by utilizing the zero-g environment. The diffusion coefficient in unit gravity was 50 times the zero-gravity diffusion coefficient of Skylab. This order of difference was attributable to unit gravity convective velocity of only 4.16×10^{-4} cm/sec in magnitude. The convective-free diffusion coefficient of Skylab was found to be $D=9.17 \times 10^{-4} \exp -(5{,}160/RT)$ cm 2/sec for the temperature range from 693°K (420°c) to 973°K (700°c).
Directional Solidification of InSb Alloys	Prof. W.R. Wilcox Univ. of Southern California Los Angeles, CA. 90007	Skylab	To investigate whether grain in indium antimonide crystals are generated by the compositional variations arising from hydrodynamic fluctuations in the melt.	Solifidication experiments performed on InSb - GaSb alloys in both space and on Earth showed no dramatic differences in grain size; however, among space processed samples a wide range of grain sizes was observed, with no influence of growth conditions yet observed. The number of twins in the space processed samples was much less than in the earth-processed samples. Equilibrium between the growing crystal and the bulk melt was more nearly achieved in the

					horizontally processed ingot, because of the enhanced free convection. Gas bubbles were trapped in the ingots when the ampules were back-filled with helium. The bubbles were more evenly distributed in the Skylab ingots. Microcracks were more numerous in inhomogeneous regions of the ingots. The ingots formed in SL-3 had a smaller diameter than the tube, but those in SL-4 did not. The grains were very difficult to distinguish from one another in five out of six Skylab ingots.
Zero Gravity Flammability	Mr. J.H. Kimzey Johnson Space Center Houston, TX. 77058	Skylab 4	Feb 4, 1974	To note the extent of surface flame and propagation and flash-over to adjacent materials, rates of surface and bulk flame propagation, self-extinguishment and extinguishment by both vacuum and spray water.	1) Burning rates were significantly reduced 2) Surface burn was not followed by continued inward burning. 3) Ignition and extinguishment appeared to be similar to to one-g.) 4) Typical blue flame and smoke pattens were noted.
Surface-Tension-Induced convection	Dr. R.E. Reed Dr. Volhoff Dr. H. L. Adair Oak Ridge National Laboratory, Oak Ridge, Tenn.	Apollo-Soyuz Test Project	1975	To investigate compositional induced surface tension-driven convection in wetting and non-wetting containers in a low-g environment.	Analysis of the low-g pressure bonded samples showed that the gold moved about one-half the distance in the low temperature ampoule as in the high temperature ampoule, as would be expected from diffusion theory. Some distortion of the diffusion profile was observed near the walls, and this distortion seems to depend on the sample orientation in the furnace. This suggests that either volume change or segregation effects during solidification may have been partially responsible for this effect. No difference was observed between samples processed in the steel and graphite ampoules. Apparently the melt did not wet the steel as expected. Marangoni convection offers the best explanation for the observed distribution,

CATEGORY 2 (continued)

					and therefore the "non-slip" boundary condition apparently does not apply to nonwetting materials in low-g.
Solidification Studies of Nb-Ge Alloys	L.L. Lacy, et.al. Exxon Corporation Houston, TX Sponsor: NASA	Drop Tower	Dec. 81	To investigate the solidification of Nb-Ge alloys after deep undercooling.	Samples have been supercooled as much as 500^{0}K below the liquidus by using free-fall conditions to eliminate crucible-induced nucleation. Final microstructures are dependent on the quenching rates at the bottom of the drop tube -- a striking extension of the B phase solubility limit.
Thermocapillary Flows and Their Stability: Effects of Surface Layers and Contamination	Dr. S.H. Davis Northwestern Univ.		June 1980 To June 1983	To theoretically analyse fluid mechanics and heat transfer of motions driven by surface-tension gradients. An understanding of the convection accompanying the process of growing high-quality crystals in a low-g environment.	Work has been completed on several uncontaminated thin-film flows. These include the steady flow due to differential heating of a cavity and the instability characteristics of such flows. It is found that for small Prandtl numbers purely mechanical instabilities occur, while for large Prandtl numbers thermal instabilities dominate. In all of the above analyses, the flows, the heat transfer, and the free surface shapes are simultaneously obtained.
Liquid Spreading	Dr. S. Bourgeois Lockheed	Apollo-Soyuz Test Project	1975	To investigate the spreading of liquids over solid and liquid interfaces and to measure the shape of the spreading liquid and the rate of spreading.	Poor quality of the photography did not allow a definitive analysis to be made.
Chemical Foams	Dr. P.G. Grodzka Lockheed	Apollo-Soyuz Test Project	1975	To investigate the stability of a liquid foam in the absence of liquid draining from thin walls; to determine whether increased stability and surface area might influence the rate at which chemical reactions take place.	Due to equipment malfunction no definitive data were obtained. However, flights in the KC-135 indicated somewhat faster reaction rates in the low-g tests than in the ground control tests.

CATEGORY 2 (continued)

Semiconductor Material Growth in Low-G Environment	R.K. Crouch A. L. Fripp Langley Research Center			To utilize the microgravity environment of space to investigate the effect of convection on the homogeneity and perfection of compound semiconductor crystals.	
Aggregation of Red Cells	Dr. L. Dintenfass University of Sydney	Planned for Space Shuttle Flights		1) To determine whether the size of red cell aggregates, kinetics and the morphology of these aggregates are influenced by near-zero gravity; 2) To determine whether viscosity, especially at low shear rate, is afflicted by near-zero gravity (the latter preventing sedimentation of red cells); and 3) To determine whether the actual shape of red cells changes, and whether blood samples obtained from different donors react in the same manner to near-zero gravity.	It is possible that such data, obtained under near-zero gravity, when compared with equivalent laboratory data and subsequent procedures, will form the basis for diagnostic tests. The results of these tests with compounds at different concentrations may well prove to be distinctive for blood samples from patients suffering from from different diseases.
Particle Dispersion in Liquid Metal	Dr. J. Raat General Dynamics/Convair San Diego, CA 92112	Skylab		To attain mixtures of liquid metals and solid particles which are free of solids and stabile.	For the successful preparation of composite materials by liquid-state processing in low-g environments, two requirements are fundamental: 1) complete wetting between the component materials during the liquid processing cycle; 2) maintenance of a uniform dispersion.
Foam Copper	Prof. R.B. Pond J.M. Winter Marvaland, Inc.	Space Flights	April 1978 To Oct. 1980	To implement a microgravity experiment to determine if entrapping gas bubbles during solidification in microgravity will result	A deoxidized copper specimen is prepared with a homogeneous dispersion of fine graphite and a separate source of copper oxide. At 100°C to 1150°C only the graphite remains solid serving as nucleation sites for gas bubbles.
Free Cooling at High Temperature	Dr. L.A. Schmidt National Bureau of Standards		April 1981 Cont. Task	To derive analytical formulas that express the temperature dependent specific heat and emissivity as functions of the ob-	

				served time-dependent surface temperature and rate of energy loss in a cold vacuum.	
Mass Transfer in Electrolytic Systems Under Low Gravity Conditions	Dr. C. Riley et al University of Alabama Huntsville		Sept. 1979 To June 1982	To achieve the electroformation of materials with improved or more desirable properties and to better understand the transport of inert suspensions during the electrode position process.	Electrodeposition cells are being utilized to study simple metal-in/metal-out reactions using cobalt and copper. The density flow patterns between electrodes with both a vertical and horizontal configuration are being bench characterized using interferometry detection. These results are being compared to those determined for the same cells under reduced gravity conditions ($\sim 10^{-2}$g) produced during parabolic, free-fall flights of a KC-135 aircraft. A special vibration free interferometer was developed to monitor flow during these flights. Studies with neutral buoyancy particles are to be used to model the transport of neutrals under low gravity conditions.
Production of Large-Particle-Size Monodispersed Latexes in Microgravity	Lehigh Univ. J.W. Vanderhoff F.J. Micale M.S. El-Aasser	Planned for Space Shuttle Flights	Feb. 1978 to Feb. 1983	To explore the possibility of preparing large particle-size monodisperse latexes in microgravity in order to avoid the problems of coagulum formation, as well as creaming and sedimentation, as the particles grow in size and change density.	
Liquid Phase Miscibiltiy Gap Materials	S.H. Gelles, S.H. Gelles Assoc. A.J. Markworth, Battelle Columbus Labs	Planned for Space Shuttle Flights	April 1978 To April 1983	To determine the manner in which the microstructural features of liquid-phase miscibility gap alloys develop.	The results of such a determination should make it possible to control the microstructures and the resultant properties of these alloys.
Solution Growth of Crystals in Zero-Gravity	Dr. R.B. Lal Alabama A&M Univ. Dr.R.L. Kroes	Possible Space Lab 3	June 1978 To June 1983	1)to grow TGS crystals from aqueous solution in low-gravity 2) to investigate mass transport and heat flow in a diffusion-	

CATEGORY 2 (continued)

	MSFC			controlled growth system, and 3) to evaluate the feasible advantages and technical potential of producing solution growth crystals in space.	
Microgravity Silicon Zoning Investigation	Dr. E.L.Kern, Consultant, G.L.Gill Westech Systems, Inc. Prof. Oscar Stafsudd, UCLA	Future Space Flight	July 1982 To July 1983	To grow uniform silicon crystals through the use of microgravity conditions; to grow silicon crystals with dopant or alloy content in ranges that are impossible to grow at l-g. (These crystals are needed for new infrared detection and imaging . devices).	
Aligned Magnetic Composites	Dr. D.J.Larson,Jr. Grumman Aerospace Corporation Bethpage, N.Y.	Space Flight	July 1978 To July 1983	To evaluate the impact of convection (thermal and/or solutal) or coupled convective/diffusive transport on the plane front solidification of contained binary magnetic composites.	
Directional Solidification of Monotectic and Hypermontectic Aluminum-Indium Alloys under low-g	Dr. C. Potard Centre d'Etudes Nucleaires de Grenoble.	SPAR	Sept. 1976 Cont. Task	To analyze the mechanisms involved in the composite solid structure formation obtained from a miscibility gap alloy under microgravity.	It is believed that capillarity may play an important role in phase separation in low-g.

SUMMARY OF MPS INVESTIGATIONS

CATEGORY 3

TITLE	INVESTIGATOR ORGANIZATION SPONSOR	VEHICLE	TIME FRAME	OBJECTIVE	DISCUSSION OF RESEARCH/RESULTS
Electrophoresis Technology	Dr. R. S. Snyder MSFC	Ground		1) To analyze the fluid and particle motions during continuous flow electrophoresis by experimentation and computation 2) to characterize and optimize electrophoretic separators and their operational parameters, and 3) to separate biological cells using apparatus that has been characterized or modified to perform in a predictable manner and according to procedures that have been developed to yield improved separation.	The following summarize the results: (1) experiments were designed to decouple or minimize the fluid effects due to the flow process, electrokinetic effects, and temperature gradients, (2) transparent electrophoresis chambers were built to allow measurement of internal and wall temperature while observing flow perturbations, (3) techniques were developed to map the temperature and flow fields in the chamber with small disturbance to the process, (4) the sensitivity of these chambers to lateral temperature gradients was measured and a new, all-metal chamber was designed to incorporate the improvements suggested by these experiements, (5) analysis yielded results that reproduce flow distortions observed in experimental chambers, (6) the DESAGA FF48 and Beckman continuous flow electrophoresis chambers were compared, using standard particles (fixed red blood cells) under various operating conditions. Optimum operating parameters for resolution and throughput were established and the two devices can be compared, and (7) these optimized conditions are being used for the separation of biological cells and macromolecules with reproducibility.

CATEGORY 3 (continued)

Surface Tensions and their Variations with Temperature and Impurities	S. C. Hardy National Bureau of Standards	Ground	April 1977 Cont. Task	Traditional sessile drop surface tension measurements are being used in conjunction with Auger spectroscopy and other modern surface analytic techniques to study the thermodynamics and chemistry of liquid metal interfaces.	Current research is on the application of Auger spectroscopy to liquid metal surfaces. The experiments are being conducted in a conventional Auger spectrometer with a vertical cylindrical mirror analyzer and a horizontal sample manipulator. The samples are in the form of sessile drops which permit the surface tension to be measured simultaneously with the Auger spectrum. Initial work with gallium drops has been promising because it was found that the surface of the drop can be cleaned by sputtering with argon ions. Fluid flows are generated in the sputtering which draw solid impurities such as oxides into the ion beam where they are sputtered away. The mechanism generating this flow is not yet identified.
Oxide Glass Processing in Space	Mr. R.A. Happe Rockwell International Space Division	Skylab		To highlight experimental work conducted over the years leading to the production of useful new optical glasses in space.	Recent experiments, which have resulted in the formation of 1/4 inch diameter glass samples from two compositions, suggest that containerless melting and cooling as envisioned for space operations are of real technological significance.
Purification and Cultivation of Human Pituitary Growth Hormone-Secreting Cells	W. C. Hymer Penn State Univ.		June 1981 To June 1982	To address the problem of 1) separation of the pituitary growth hormone cell, 2) its maintenance in vitro, and 3) the role that gravity plays in establishing limits at these current lab technologies.	A human pituitary column perifusion method was developed to sustain hGH release from pituitary tissue over extended periods (1-3 days). On the basis of experimental results from 144 human pituitary glands removed 1-18 hours, postmortem, it was found that protaglandin E_1 (10^{-9}M)or epinephrine (10^{-9}) stimulates release of a "GRF" from rat hypothalmi which is, in turn, capable of sustaining hGH release for at least 24 hours. Tissue samples stained immunocytochemically for hGH cells reveal large numbers of well-preserved cells in this

CATEGORY 3 (continued

					experimental protocol. These results support the notion that the human postmortem pituitary gland contains functional growth hormone cells. Results from numerous experiments demonstrate that we can prepare $\sim 15 \times 10^{-3}$ cells/mg postmortem human pituitary tissues. These cell preparations are $\sim$ 80% viable, and by electron microscopy contain membrane and granule systems characteristic of intact tissue. Concerted efforts were made to separate GH cells from both rat and human pituitaries by chemistry gradient electrophoresis. Results indicate that somatotrophs (GH cells) apparently have low electrophoretic mobilities, and possibilities for their eventual purification by this technique appear encouraging. Finally, a methodology has been developed for the implantation of human pituitary cells in rats. With this methodology it should be possible to assess a function of hGH cells <u>in vitro</u>, and eventually isolate hGH from the animal.
Undercooling Studies in Metastable Peritectic Compounds	M.B. Robinson Marshall Space Flight Center	Ground	March 1979 To March 1982	To investigate undercooling and containerless solidification of metastable superconducting alloys Nb_3Ge and Nb_6Al pure metal melts such as Nb.	Undercooling is being measured for the NbGe alloy drops with results showing that the Nb 18 a/o Ge drops undercooled 500 K, where the Nb 22 a/o Ge drops undercooled 300 K. These undercoolings do not represent the maximum extent possible since these drops undercool the complete length of the drop and nucleated only after reaching the catcher. An increase in the transition temperature of the heavily undercooled NbGe drops have a measured transition temperature of $\sim$ 10K which is 4K above the cast materials. The increase indicates

					that at least some of the metastable A15 structure has been formed. The presence of the metastable A15 phase has been confirmed by X-ray diffraction, compositional analysis using EDAX and further microstructural analysis.
Vapor Growth of Alloy-Type Crystals	Dr. Herbert Weidemier Polytechnic Institute	Ground	March 1978 To March 1983	To investigate, through systematic ground-based studies, the effects of gravity-crystals of alloy-type semiconductors; to define optimum conditions for the growth of these materials in a microgravity environment, and to perform crystal growth studies in space.	Present results reveal that the surface morphology and chemical homogeneity of Hg_8Cd_2 Te crystals obtained under vertical stabilizing conditions are improved relative to crystals grown under horizontal conditions. The crystal quality of $CuInS_2$ shows similar improvements for the horizontal ampoule configuration with decreasing pressure (decreasing convective interference) of of the system. The combined results of ground-based studies will lead to the definition of optimum growth conditions for the actual space experiments.
Fluid Dynamics of Crystallization from Vapors	Dr. F. Rosenberger Univ. of Utah Salt Lake City	Ground	June 1978 Cont. Task	To obtain a fundamental insight into the complex physiochemical fluid dynamics of closed ampoule vapor crystal growth processes to the extent that a desired set of crystal growth conditions can be designed in advance.	Numerical modeling of vapor transport in vertical ampoules shows that diffusion fluxes, in viscous interaction with the wall, establish density gradients normal to the main transport direction. These density gradients act convectively, destabilizing even in ampoule orientations which, classically, were considered convection free (e.g., "heating from top"). Also, it was demonstrated that the convection behavior in crystal growth ampoules can not be extrapolated from known solutions to fluid dynamically "similar" monocomponent (pure) systems. The net transport across the vapor space causes drastic changes as compared to convection patterns in cylinders with impermeable end faces. It was found experimentally that thermal

					diffusion in ampoules acting convectively were more destablizing than in laterally unbound geometries. Modeling of vapor transport across a horizontal cavity has shown that at lower transport rates earlier, simplifying treatments (Klosse-Ullersma, KU), because of fortuitous cancellation of errors, give reasonable results for two-dimensional systems. However, laser Doppler anemometry studies of the convective velocity fields in inclined and horizontal ampoules revealed three-dimensional features of the flow that had generally not been accounted for in modeling. Titrometric and vapor pressure studies have shown that deviations in stoichiometry of mercuric iodide (HgI_{2+x}) can extend to $x = -3 \times 10^{-3}$. No excess in iodine, i.e. $x > 0$, could be detected in vapor--and solution-grown samples obtained from various sources.
Experimental and Theoretical Studies in Wetting and Multilayer Absorption	Dr. M.R. Moldover Dr. J.W. Schmidt Dr. J.W. Cahn National Bureau of Standards	Ground	April 1981	To use optical techniques to measure the thickness of the layer which intrudes between the upper liquid phase and the vapor at the liquid vapor interface above 3 different transparent binary solutions and one transparent tertiary solution	Measured thickness range from 60Å - 400Å. A phase transition, at which the thickness of an intruding layer increases from less than 20Å to approximately 400Å as a two phase liquid sample is heated less than 0.05°C, was discovered. A theory was developed for phase equilibria among grain boundary structures and for transitions between various grain boundary phases.
Glass Shell Manufacturing in Space	Dr.Robert L. Lolen KMS Fusion, Inc. Ann Arbor, Mich.		Dec. 1978 To Dec. 1981	To develop a detailed understanding of the chemical and physical processes involved in the formation of uniform, high-quality spherical glass shells.	The temperature regimes where major transformations occur in the shell starting materials (metal-organic gels) were identified by using a combination of thermal, analytical techniques. The gases generated by pyrolysis of the gel were

					quantitatively characterized by gas chromatography and pressure tests. Computerization of a mathematical model of the heat transfer mechanisms will be used to bring it into line with the results from a series of controlled drop tower furnace experiments to be done with fully characterized and standardized gel power pellets.
Advanced Methods for Preparation and Characterization of Infra-red-Detector Materials	Dr. J. G. Broerman et.al., McDonnald Douglas Research Labs	Ground		To quantitatively establish the characteristics of $Hg_{1-x}Cd_xTe$ as grown only on Earth (1-g) as a basis for subsequent evaluation of the material processed in space, and to develop experimental, theoretical and analytical methods required for such evaluation.	Theoretical models and computer programs specific to $Hg_{1-x}Cd_xTe$ were developed for calculations of charge-carrier concentrations, Hall coefficient, Fermi energy, and conduction electron mobility as functions of x, temperature, ionized-defect and neutral-defect concentrations. A comparison of calculated results with available experimental data indicated that longitudinal optical-phonon and charged and neutral defect scattering are the dominant mobility limiting mechanisms.
Defect Chemistry and Characterization of (HgCd) Te	Dr. H.R. Vydyanath Honeywell	Ground	Dec. 1978 To March 1982	To study the nature and concentration of the lattice defects incorporated into $(Hg_{01-x}Cd_x)$ Te Alloys as a function of the physiochemical conditions of preparparation.	At the end of the 24 month period of the program, significant accomplishments have been made toward understanding the nature of lattice defects and the mode of incorporation of different dopants. For the first time in literature, the defect structures of undoped $Hg_{0.6}Cd_{0.4}Te$ (s), copper doped, indiumdoped, and iodine doped, phosphorus doped $Hg_{0.8}Cd_{0.2}Te$ (s) have all been established. The native acceptor defects have been found to be doubly ionized in both $Hg_{0.6}Cd_{0.4}Te$ (s) and $Hg_{0.8}Cd_{0.2}Te$ (s). Native donor defects are found to be negligible in concentration in these alloys and the origin of p-type to n-type conversion has been shown to be due to residual foreign donors and not due to

					native donor defects. Of the dopants studies, copper and indium were found to occupy only Hg lattice slits acting with single acceptor and donor electrical activities respectively, whereas iodine is found to act as a single donor occupying only Te sites. A large concentration of indium is found to be incorporated in In_2Te_3 with only a small fraction acting as donors. Crystals doped with iodine are found to be saturated with the metal iodide, with a large fraction of iodine being paired with the native acceptor defects. Crystals doped with phosphorus behave amphoterically, acting as a donor on Hg lattice sites and as an acceptor interstitially and on Te lattice sites. Thermodynamic constants have been established for the incorporation of the native defects as well as the different dopants. These constants satisfactorily explain all the experimental results.
Ultimate Intrinsic Coercivity $SmCo_5$ Magnet	Dr. Dilip Das Charles Stark, Draper Laboratory Dr. R.T. Frost General Electric	Ground	Sept. 1979 To July 1982	To produce Sm-Co magnets of reasonably high maximum energy product with intrinsic coercivity.	In preparation for the design of a high quality comminution and encapsulation chamber, some preliminary comminution experiments in a laminar flow nitrogen glove box are being performed. The oxygen pickup in the above powder has been reduced by 60 percent over the power prepared in the air. Based on this encouraging result, using a high quality chamber in a pure quiescent nobal gas should lower the oxygen content to a few decades of ppm instead of the 0.6 weight percent in the state-of-the-art magnets.

CATEGORY 3 (continued)

					A comminution chamber was built by an outside vendor and has just been installed at the Draper Laboratory. The chamber is capable of attaining 10^{-6} torr pressure, and can be back filled with purified Argon gas with an oxygen level of 0.1 ppm by weight. Experiments to achieve powder comminution compaction and encapsulation of compacts in the oxygen-free atmosphere inside the chambers will commence soon. Further experiments in R.F. levitation melting of $SmCo_5$ alloy do not result in significant lowering of oxygen content. However, some $SmCo_5$ alloys with very low oxygen and other contaminant contents have been produced using the expertise and facilities at the Ames Laboratory of Iowa State University.
Studies of Model Immiscible Systems	D.O. Frazier et al MSFC	Ground	Oct. 1979 To Oct. 1982	To use model organic immiscible systems to obtain fundamental information applicable to two-phase systems in general, and to apply this understanding to materials of interest in the Materials Processing in Space Program in order to interpret results of flight experiments involving monotectic alloys.	Data with respect to solidification of succinonitrile/water solutions are thus far consistent with critical point wetting behavior and Marangoni effects. There is experimental evidence that wetting phenomena are observable by holographic photography. Solid-liquid interfacial free energy differences are, in principle, accessible by film pressure (via ellipsometry) measurements. Viewing holographic studies and interfacial free energy measurements in light of segregation profiles of model solidified ingots should yield valuable verification of operational limits.
Directional Solidification of Liquid Misibility	Dr. M.H. Johnston Marshall Space Flight Center	Ground		To identify the influence of gravity on the aligned structure in liquid miscibility gap materials. This includes establishing the true monotectic composition and determining	

CATEGORY 3 (continued)

			the solidification mechanism's possible dependence on undercooling.	
Analysis of the Float Zone Process	Prof. R.A. Brown Mass. Institute of Technology Cambridge, MA. Sponsor: NASA	Ground base	Directed toward a fundamental understanding of the interaction of heat, mass, and momentum transfer in the floating zone method for growing single crystal from the melt.	Results of this study are being used to describe radial and axial segregation in systems operating in low-g conditions.
Solutal Convection and Its Effects on Crystal Growth and Segregation in Binary and Pseudo-Binary Systems with Large Liquidus-Solidus Separation	Dr. Edith D. Bourret MIT	Ground	To theoretically and experimentally study the effects of solutal convection on segregation in binary and pseudo binary systems with large liquidus solidus separation (i.e. 6c-Si, $Hg_{1-x}Cd_xTe$, $Pb_xSn_{1-y}Te$).	
Transient Convective Heat Transfer in Zero gravity	Dr. V. Arp Dr. R. Noble National Bureau of Standards Boulder, Colorado	Ground	To separate the gravitational contribution from dynamic heat and mass transfer measurements, thus allowing a more accurate comparison with theory, leading to improved engineering correlations.	Two types of mass transfer experiments are envisioned. In the first, an ionic solution is isolated from a pure component intially. The barrier is removed and the resulting diffusion is monitored. In the second type of experiment, an ionic solution would be exposed to an external applied field and the resulting diffusion monitored.
Study of Eutectic Formation	Dr. W. R. Wilcox Clarkson College	Ground	To investigate the theoretic influence of convection on lamellar spacing of a eutectic and to develop a technique for revealing the longitudinal microstructure of the MnBi-Bi eutectic.	

CATEGORY 3 (continued)

Transient and Diffusion Analysis of HgCdTe	Dr. J. Creed Clayton Semtec, Inc. Huntsville, Ala. Sponsor: NASA	Ground		To analyze the directional solidification of the alloy systems HgCdTe in order to obtain optimim processing conditions for crystal growth.	
Blood Flow in Small Vessels	Dr. G. R. Cokelet Dr. H. Meiselman Dr. H. Goldsmith	Ground		To obtain ground-based data for establishment of flight test conditions and to test potential flight experiment components; to study the flow of blood under low shear stresses in red cell sedimentation.	
Advanced Methods for Preparation and Characterization of Infrared-Detector Materials	Dr. S.L. Lehoczky F.R. Szofran B.G. Martin McDouglas Research Laboratories St. Louis, Mo.	Ground	Dec. 1978 to Dec. 1981	To quantitatively establish the characteristics of Hgl-x Cdyte as grown on Earth (l-g)as a basis for subsequent evaluation of the material processed in space, and to develop experimental, theoretical, and analytical methods required for such evaluation.	Theoretical models and computer programs specific to Hgl-x CdyTe were developed for calculations of charge-carrier concentrations, Hall coefficient Fermi energy, and conduction electron mobility as functions of x, temperature, an ionized-defect and neutral defect concentrations. A comparison of calculated results with available data indicated that longitudinal optical-phonon and charged and neutral defect scattering are the dominant mobility limiting mechanisms.
Analysis of the Float Zone Process	Prof. R.A. Brown MIT	Ground		To achieve a fundamental understanding of the interaction, of heat, mass, and momentum transfer in the floating zone method for growing single crystals from the melt.	
Solutal Convection During Directional Solidification	S.R. Coriell R.S. Schaeffer National Bureau of Standards	Ground		To calculate and measure effects of convection caused by simultaneous temperature and concentration gradients on directional solidification, including a determination of segregation effects in experiments done on Earth and an estimation of the effect of	

				microgravity and magnetic fields in avoiding such convection.	
Fluid Motion in a Low-G Environment	Dr. P.G. Grodzka Lockheed Missiles and Space Company	Skylab		To review the state of knowledge of fluid motions in low-g environments.	
Electrostatic Control and Manipulation of Materials for Containerless Processing	Dr. D.D. Elleman Dr. W. K. Rhim Jet Propulsion Laboratory		October 1978	To develop electric field positioning/manipulation techniques and technology for the containerless processing of materials in bulk and dispersed forms.	
Liquid Metal Diffusion in Solubility Gap Materials	Prof. R.B. Pond J.M. Winter Marvaland, Inc. Westminster, Md.	Ground	April 1978 To Sept. 1980	To measure the diffusion rates of two liquid metals. The intermediate objective is to verify or disprove the suspicion that determining diffusion constants of solubility gap liquid metals in one "g" experiments will lead to erroneous results due to density-driven convection motion.	It is expected that the final determination will have to be gained under microgravity conditions.
Analytical Approach to Modeling of Heat Flow in Bridgman-Type Crystal Growth	Dr. R.J. Nauman Ms. Ernestine Cothran Marshall Space Flight Center, Ala	Ground	Oct. 1980 To May 1981	To develop an analytical approach to the modeling of heat flow in Bridgman-type crystal growth.	One-dimensional models have been used to estimate the thermal profiles, determine the position and motion of the growth interface, and assess the axial thermal gradients in the sample as functions of furnace and sample parameters, sample insertion length, and sample motion. A two-dimensional analysis has also been developed which can accommodate different thermal properties of the sample in the melt and solid phases and can locate the position and determine the shape of the solidification interface in a 3-zone furnace which included an insulated or adiabatic zone. It has also

CATEGORY 3 (continued)

					been shown that the maximum axial gradient in a long cylindrical sample that can be obtained by the Bridgman technique is approximately 2/3 times the difference between the hot and cold end temperatures divided by the sample radius.
Direct Observation of Interface Stability	Prof. W.A. Tiller Prof. R.S. Fiegelson Dr. D. Elwell Stanford Univ.	Ground	Dec. 1978 To Jan 1982	To test the theory with the experimentation on a model system, including a measurement of all significant material parameters of the system.	
Physical Phenomena in Containerless Glass Processing	Dr. R.S. Subramanian Dr. R. Cole Clarkson College of Technology	Ground base	Dec. 1977 to Dec. 1982	To study the behavior of gas bubbles inside drops of model fluids and molten glasses in free fall, focusing on their migration and interaction.	The results of the experiments are expected to be of use in the development of techniques for mixing and firing glasses in space and in providing a better understanding of how microballoons are formed.
Fluid Dynamics of Crystallization from Vapors	Dr. F. Rosenberger University of Utah Salt Lake City	Ground	June 1978 To May 1981	To obtain a fundamental insight into the complex physiochemical fluid dynamics of closed ampoule vaopr crystal growth processes; to synthesize ultrapure mercuric iodide and the vapor composition (stoichiometry) required for the growth of mercuric iodide high resolution radiation detector crystals.	Numerical modeling of vapor transport in vertical ampoules has shown that diffusion fluxes establish density gradients normal to the main transport direction. These density gradients act convectively destabilizing even in ampoule orientations which were consdiered convectionfree.
Growth of Solid Solution Crystals	Dr. L.R. Holland Athens State College Athens Alabama Dr. A.F. Witt MIT Dr. D.B.Schenk, BMD-ATC		Oct. 1977 to Oct. 1982	To determine the conditions under which single crystals of solid solutions can be grown from the melt in a Bridgman configuration with a high degree of chemical homogeneity. The central aim of this program is to assess the role of gravity in the growth process and to explore the possible advantages for growth in the absence of gravity.	The problems of purity and containment in quartz ampules were resolved. The necessary purity and the resulting absence of chemical attack on the quartz are achieved by obtaining ultrapure starting material and loading by distillation. The structural integrity of the ampoules at the high vapor pressures associated with growth of this system was demonstrated. Crystals were grown by the Bridgman method and analyzed

CATEGORY 3 (continued)

					by the energy dispersive X-ray technique (Kevex). Composition was determined longitudinally and radially. These compositional profiles are being analyzed by one-dimensional models. In addition to the basic studies, thermal profiles were determined to obtain the optimum growth environment for the HgCdTe material.
Float Zone Experiments in Space	Dr. J. D. Vethoeven Ames Laboratory Iowa State Univ.	Ground	Oct. 1981 To Oct. 1982	To determine if surface tension-driven convection in a float zone can be controlled or eliminated by means of surface film; and to investigate solute distribution and measure liquid diffusion coefficients in floating zones.	
Vapor Phase of PbSnTe	JA Zoutendyk Jet Propulsion Laboratory	Ground base	March 1981 To March 1982	To experimentally study the gravity-driven convection effects in the growth of PbTe and CdTe crystals by physical vapor transport.	
Growth of Solid Solution Crystals	Dr. S.L. Lehoezky, MSFC Dr. F.R. Szofran, MSFC Dr. L.R. Holland, UAH Dr. J.C. Clayton, Semtec Dr. D.C. Gillies, Semtec	Ground	Oct. 1977 To Oct. 1982	To determine the conditions under which single crystals of solid solutions can be grown from the melt in a Bridgman configuration with a high degree of chemical homogeneity. The central aim of this effort is to assess the role of gravity in the growth process of single crystals of solid solutions and to explore the possible advantages for growth in the absence of gravity.	
Dendritic Solidification at Small Supercoolings	M.E. Glicksman Rensselaer Blytechnic Institute	Ground	March 1977 To June 1982	To obtain information relating to the kinetic and morphological behavior of systems solidifying at small supercoolings with respect to the role of convective and diffusive transport and the influence of gravity.	These studies provide important data on the fundamentals of solidification at normal terrestrial and reduced gravitational levels. The large data base now established for high-purity succinonitrile (SCN) permitted the most comprehensive check of diffusional dendritic growth theory and the

CATEGORY 3 (continued)

					development of scaling laws permitting the extension of these theories to many other material systems.
Fluid Dynamics Numerical Analysis	Dr. L.W. Spradley Dr. J. Robertson Lockheed Missiles and Space Company	Ground	August 1979 To August 1982	To compute transient thermal convection for cases of importance to materials processing in space. This includes problems too difficult for analytical solutions.	Currently underway is a calculational effort to determine the effect of container shape on the magnitude of microgravity convection.
Containerless High Temperature Property Measurements by Atomic Fluorescence	Dr. P.C. Nordine Yale University	Ground	June 1980 To May 1983	To measure high temperature properties in containerless experiments using laser excited atomic fluorescence, and to develop new techniques for an earth-based study of candidate space labs high temperature experiments in MPS applications.	Specimen vapor pressure, temperature, or evaporation rate, gas phase transport properties, or gas phase reaction rate constants are being determined.
Ultrapure Glass Optical Waveguide Development in Microgravity by the Sol-Gel Process	Dr. S.P. Mukherjee Battelle Columbus Labs	Ground	June 1982 To June 1983	1) To study the homogeneity of gels and gel-derived in the oxide systems which are potentially important in the field of optical waveguild applications 2) to study the glass formation ability of certain compositions in the selected melting of homogenesis multicomponent noncrystalline gels. 3) to study the influence of impurities obtained from the containers of the glass formation ability and 4) to perform containerless melting of ultrapure multicomponent gels and evaluate their purity and crystallinity.	Results of the studies of the oxide systems SiO_2-GeO_2, SiO_2-TiO_2, and GeO_2-PbO/Bi_2O_3 are being critically analyzed for the selection of one particular system for the containerless processing of ultrapure gels in the microgravity environment of space.

CATEGORY 3 (continued)

Aligned Magnetic Composites	Dr. D.J. Larson, Jr. Grumman Aerospace Corp.	Ground	July 1978 To July 1983	To contribute to an understanding of the role of convection on plane front solidification of eutectic and peritectic composites and the relationships between morphology and magnetic properties.	
The Influence of Gravity on the Solidification of Monotectic Alloys	Dr. A. Hellawell Michigan Technological Univ.	Ground	Sept. 1980 To Sept. 1983	To examine the monotectic reaction, using directional solidification methods, in order to obtain aligned composite structures; to identify the gravitational influence on separating two liquids below a miscibility gap and incorporating them within a duplex growth front.	The systems under examination include Al-In, Cu-Pb, Al-Bi, Cd-Ga, and a transparent analogue $(CH_2CN)_2 - H_2O$ as well as the ternary systems Al-In-Sn, Cu-Pb-Al and Cd-Ga-Al. The transparent analogue system is being examined in a temperature gradient stage on an optical microscope in order to study the detailed form of the duplex, solid + liquid growth front.
Theoretical Studies of the Surface Tension of Liquid Metals	D. G. Stroud Ohio State University	Ground	Feb. 1982 To Feb. 1984	To develop a theoretical understanding of the surface tensions of liquid metals, and of their temperature and concentration derivatives.	
Measurement of the Properties of Tungsten at High Temperatures	Dr. J. Margrave Rice University	Ground	Nov. 1978 To March 1985	To measure the thermophysical properties of tungsten and tantalum using containerless techniques.	Heat capacities are determined from cooling curves, and/or dropping the molten metals in a drop calorimeter. Enthalpy increments and heat capacities and emissivities are being measured.
Fusion Target Technology	Dr. T.G. Wang Jet Propulsion Laboratory	Ground	Oct. 1979 Cont. Task	1) To study the physical processes that are associated with the fabrication of inertial confinement fusion (ICF) targets in a weightless environment, 2) to determine jointly with DOE centers the need for extended 0-g in future production of ICF targets. 3) to provide technological information to DOE centers.	

CATEGORY 3 (continued)

Binary Miscibility Gap Systems	Dr. V.A. Schmid National Bureau of Standard	Ground	April 1981 Cont. Task	To exploit the thermocapillary migration effect in the design of a controllable heat valve which is the thermal analog of an electronic vacuum triode.
Interfacial Destabilization in Metal Alloys	Y. Malmejac J. J. Javier Laboratoire d'Etudes de la Soldification Centre d'Etudes Nucleaires de Grenoble	Ground	Jan 1980 Cont. Task	To study the destabilizing mechanisms that affect a crystal growth interface; to obtain information on destabilizing morphologies in the steady and transient states and on growth kinetics behavior; and to attempt to separate the influence of liquid phase instabilities from the interface instability.
Crystal Growth of Device Quality GaAs in Space	Prof. Gatos Dr. Jacek Lagowski MIT	Ground	April 1977 Cont. Task	To establish relationships among crystal growth parameters, materials properties, electronic properties and device applications of GaAs. This will constitute a necessary step toward insuring successful processing of GaAs under zero gravity conditions.
Advanced Containerless Processing Technology	Dr. T.G. Wang Jet Propulsion Laboratory	Ground	October 1970 Cont. Task	1) To study the contactless positioning and manipulation of a high temperature acoustic chamber 2) to provide design information on a flight version of this chamber for materials science studies in a contactless and zero gravitation environment 3) to provide a set of ground-base facilities to perform precursor experiments.
Transient Thermal Convection in Low-g	Dr. R.F. Dressler NASA HQ		Jan. 1980 Cont. Task	To obtain analytical solutions for transient and periodic convection flows for arbitrary low-g excitations with imposed thermal gradient in cylinders and cubes for both 2-b and 3D flows.

SUMMARY OF MPS INVESTIGATIONS

CATEGORY 4

TITLE	INVESTIGATOR ORGANIZATION SPONSOR	VEHICLE	TIME FRAME	OBJECTIVE	DISCUSSION OF RESEARCH/RESULTS
New Polymers for Low-gravity Purification of Cells by Phase Partitioning	J. Milton Harris Univ. of Alabama Huntsville	Ground		To produce materials which will aid in space experiments to separate important cell types; and, to study the partitioning process in the absence of gravity, (i.e. in an equilibrium state).	Three new types of water-soluble polymers were synthesized. These are: (1) polyethylene glycols with attached crown ethers; (2) polyethylene glycols with attached cyclodextrins; and (3) dextans with attached long-chain hydrocarbons. The crown ethers and cyclodextrins are of interest because of their ability to selectively form complexes with, respectively, metal cations and hydrophobic anions. These nitrogen crowns upon protonation should also bind hydrophobic anions. Consequently, these materials present the possibility of specifically binding groups on the cell surface. The polymers with long-chain hydrocarbons attached are of interest because of the probable attraction of the hydrocarbon for lipophilic areas on the cell surface. Testing of the properties of these new materials has begun. An interesting spin-off has been the observation of catalytic activity for the crown polymers.
Measurement of High Temperature Thermophysical Properties of Tungsten Liquid and Solid	Dr. D. W. Bonnell National Bureau of Standards			To evaluate experimental procedures used in the interaction between General Electric Advanced Application Laboratory (GE) and Rice University, to measure the high temperature enthalpy increments of liquid and solid Tungsten.	

CATEGORY 4 (continued)

Gel Precursors as Glass and Ceramic Starting Materials for Space Processing Applications Research	Dr. R. L. Downs W. J. Miller KMS Fusion, Inc.			To determine experimental procedures used to produce gels starting materials for investigations of containerless processing in space.
Acoustic Positioning for Containerless Processing	Dr. R.R. Whymark Intersonics Inc. Chicago, Ill. 60611	Skylab		To describe a new type of acoustic position control system that can be adapted to space processing chambers with minimum modification to the chambers.
Electromagnetic Containerless Melting and Solidification in the Weightless Environment	Dr. R.T. Frost General Electric, Philadelphia, Pa. 19101	Skylab		To indicate general facility concepts capable of processing the widest possible range of important containerless processing experiments within reasonable technology constraints.
Characterization of Semiconductor Materials	Dr. D.C. Gillies Universities Space Research Association Columbia, Md.	Ground	Oct. 1980 To Oct. 1981	To develop techniques for characterizing high-quality, solid solution, alloy type semiconductors for use as infrared detectors or as IR transparent substrates.
Hormone Purification by Isoelectric Focusing in space	Dr. Milan Bier Univ. of Arizona-Tucson	Ground	March 1978 To March 1982	To study the effects of gravity on the isoelectric focusing process; to define and produce a definite isoelectric focusing experiment, and, to refine future isoelectric focusing technology.
Rework of the SPAR Electromagnetic Levitator (EML) for Materials	Dr. R.T. Frost General Electric Co.	Planned for Shuttle Flights	October 1981 To Oct. 1982	To study the upgrade requirements and approaches needed for incorporation of an EML in the MEA carrier; to design and develop an engineering version of

CATEGORY 4 (continued)

Experiment Assembly (MEA) Accommodation				multisample specimen exchanger; to develop and test improvements in high temperature drop colorimetry techniques including new techniques for low gravity work; and, to carry out support tasks for the electromagnetic containerless processing Task Team.	
Mathematical Models of Continuous Flow Electrophoresis	Dr. D.A. Saville, et.al. Princeton Univ.	Ground	August 1977 To Feb. 1983	To develop a comprehensive model of the actual 3-b flow temp. and electrical fields; to provide guidance in the design of electrophoresis chambers for specific tasks and means of interpreting test data on a given chamber.	Verification of the model is to provide the support necessary for the interpretation of microgravity operations. Recommendations are to be made for the design and operations of the ground experiments.
Modeling Directional Solidification	Dr. W. R. Wilcox Clarkson College of Technology	Ground	May 1982 To May 1985	To develop tools used in explaining results of directional solidification in space.	
Dynamic Thermophysical Measurements in Space.	Dr. A. Cezairliyan National Bureau of Standards		April 1981 Cont. Task	To develop techniques for the dynamic (subsecond) measurement of selected thermophysical properties (such as heat capacity, heat of fusion, electrical resistivity) of solids and liquids at temperatures above 2000K in experiments to be performed near-zero-gravity environment.	Under the near-zero-gravity conditions, it might be possible to sustain a liquid column (specimen) for the duration of the brief experiment and thereby obtain, for the first time, accurate thermophysical properties data above the melting point of high melting substances.
Biosynthesis/Separation Laboratory-Development of a Space Biosynthesis System and Biological Studies for Electrophoresis in Space	Dr. D.R. Morrison Mr. Bernard J. Mieszke	Ground	Jan. 1981 Cont. Task	1) To obtain data on the performance of cell culture vessel system elements and to define their biological oxidational process and, 2) determine the limits of ground-base technology using a preprototype reactor for studying enzymatic reactions and suspension cell cultures.	

APPENDIX B

BIBLIOGRAPHY

APPENDIX B

BIBLIOGRAPHY

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